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Condition Based Maintenance Technology Impact Study: Assessment Methods, Study Design and Interim Results

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ABSTRACT

Condition Based Maintenance (CBM) involves performing preventive maintenance actions based on evidence of need, rather than more traditional usage or time schedules. This report presents interim results from a CBM 'Technology Impact' study that aims to identify the key drivers and factors that need to be understood for CBM to be effective in the military Land domain. Following a literature review and a first round of Subject Matter Expert surveys, a 'causal impacts' map has been established. This map considers the impact of the required enablers of a CBM capability and the likely outcomes of adoption. In addition, the map captures economic and temporal considerations, and impacts on stakeholder groups and Fundamental Inputs to Capability categories. This map will be further refined and analysed as the study progresses. The study outcomes will inform capability acquisition projects and collaborative research within The Technical Cooperation Program. Ultimately this study will form a basis for a 'value proposition' framework to assess the extent to which CBM should be adopted within Land materiel maintenance.

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Executive Summary

Condition Based Maintenance (CBM) involves performing preventive maintenance actions based on evidence of need, rather than more traditional usage or time schedules. The promise of CBM is threefold: to extend the useful life and reduce the through-life cost of equipment; to improve fleet operational availability and mission effectiveness; and to reduce the maintenance burden. While well established in other military (particularly Air) and commercial domains, adoption of CBM in the military Land domain has been slow, but is now firmly underway.

It is likely that introducing CBM to support Land-based military forces will require new technological systems to be adopted. When anticipating the effects of adopting such systems, it is important to consider the associated practices, processes and policies in addition to the technology itself. Quite frequently, factors other than inherent technological merits determine the success or failure of adopting new technologies. The successful adoption of Land CBM requires that not only the potential technology barriers be identified and addressed, but also an understanding of the nuances of CBM adoption in the military Land domain.

The two most frequently cited reasons for the slow pace of adopting CBM within the Land domain are: 1) that the drivers for adoption in the Land domain are different to other domains, such as Air; and consequently 2) the difficulty of establishing a clear business case for adoption in the Land domain. The latter is made more difficult by the former. For example, in the Air domain, safety is the most critical factor and so the argument for adoption is clear. Conversely, the consequences of catastrophic equipment failure may at times be perceived as less severe in the Land domain, and hence, the safety argument tends to lose its criticality while more pragmatic economic considerations rise in prominence.

Therefore, the aim of this study is to obtain a comprehensive set of cost/benefit factors, clarify the drivers for adoption, identify the areas of most importance to stakeholders, and determine the critical issues that must be addressed in order for CBM to be effective in the military Land domain.

This report presents the conceptual model developed to describe Land CBM and the interim results of a CBM 'Technology Impact' study. The first stage involved drawing on a number of established methods and techniques to develop a general conceptual model. This model allowed us to study the impacts of introducing a new technology and identify the key drivers and factors that need to be understood for its adoption to be successful.

Having established a conceptual model, a baseline causal CBM Technology Impact 'map' was developed. This map considers the impact of the factors that enable a CBM capability and the likely outcomes of adoption of CBM. In addition, the map captures economic and temporal considerations, impacts on stakeholder groups, and impacts on inputs to the development and delivery of military capability.

The next step of the study was conducting two Delphi-like survey rounds. The first round was designed to elicit a wide variety of responses on perceived benefits, costs, and barriers to implementation of CBM in the military Land domain, as well as identifying appropriate areas for initial implementation of CBM. Following collection and compilation of first round responses, a newer version of the impact map was produced. Further, a second round of surveys was designed to refine the structure and content of the impact map, and encourage consensus amongst respondents on the relative importance of various impacts. A preliminary examination of the second round survey results is also given in this report.

The next stage of this study will involve further refining of the impact map through analysis and incorporation of the second round survey responses. The study outcomes will inform planning and investment decisions relating to the acquisition of new Land force equipment as well as adaptation of CBM for sustainment of existing fleets, and will contribute to collaborative research within The Technical Cooperation Program (TTCP). Ultimately this study will form a basis for a 'value proposition' framework to assess the extent to which CBM should be adopted within the maintenance practices of Land-based military forces.

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Abbreviations

ADF	Australian Defence Force
AG	Action Group
AHQ	Army Headquarters
CBM	Condition Based Maintenance
CDG	Capability Development Group
DIO	Defence Intelligence Organisation
DMO	Defence Materiel Organisation
DOTLMPF	Doctrine, Organisation, Training, Materiel, Leadership, Personnel, Facilities
ASD	Australian Signals Directorate
DSTO	Defence Science and Technology Organisation
EMEI	Electrical and Mechanical Engineer Instruction
FIC	Fundamental Inputs to Capability
FORCOMD	Forces Command
HUMS	Health and Usage Monitoring System
ICT	Information and Communication Technology
IDEF0	Integrated computer aided manufacturing Definition Function Modelling
IT	Information Technology
LND	Land Group
MOD	Ministry of Defence (UK)
NATO	North Atlantic Treaty Organisation
OEM	Original Equipment Manufacturer
PRICIE	Personnel, Research and development, Infrastructure and organisation, Concepts, doctrine and collective training, Information management, Equipment and material
R&D	Research and Development
SME	Subject Matter Expert
SOP	Standard Operating Procedure
SPO	Systems Program Office
TEPIDOIL	Training, Equipment, Personnel, Information, Concepts and doctrine, Organisation, Infrastructure and Logistics
TTCP	The Technical Cooperation Program
TTP	Tactics, Techniques and Procedures
UK	United Kingdom (of Great Britain and Northern Ireland)
US	United States (of America)

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1. Introduction

Broadly speaking, Condition Based Maintenance (CBM) is a maintenance paradigm that promises to: extend the useful life and reduce the through-life cost of equipment; improve fleet operational availability and combat effectiveness; and reduce maintenance burden. The basic premise of CBM is that maintenance is conducted on equipment based on evidence of need, rather than any set time or usage schedule. Evidence of need is provided by directly monitoring the condition of the equipment, or derived by evaluating equipment usage against known failure models. The use of equipment monitoring techniques also offers the potential for prognostics to predict the occurrence of failures before they occur, so that maintenance can be conducted at a time and place of choice.

The difficulty of establishing a clear business case for CBM in the military Land domain is frequently cited as a reason for its slow pace of adoption when compared to other domains, as well as in the commercial sector. For instance, catastrophic aircraft failure will tend to have disastrous consequences for crew safety, creating a strong case for adopting equipment monitoring techniques, if not CBM itself. However as the risks to a crew arising from a catastrophic failure of Land vehicles is much lower, more pragmatic economic considerations tend to hold greater prominence. This leads to a greater emphasis being placed on the economic factors when developing business cases in support of Land CBM adoption.

Traditional cost/benefit analysis that examines the economic factors of Land CBM adoption has been an active area of research and development in recent times. This includes developing new software models and tools, and adapting existing models and tools from different domains for use in the Land domain. [1] provides an overview of a number of such tools that are prominent in the literature. However, as in the Air domain, there exist drivers other than those based purely on economics.

Australia's Defence Science and Technology Organisation (DSTO) is undertaking a CBM Technology Impact' study with the following aims:

- obtain a more comprehensive set of cost/benefit factors
- clarify the drivers for adoption in the Land domain
- identify the areas of most importance to stakeholders
- identify the critical issues that must be addressed for CBM to 'work' in the military Land domain.

We propose a new 'future technology' assessment model drawing upon the most relevant elements of a number of existing models and concepts for technology diffusion and adoption. This model is populated through a Delphi-like process and this report describes the complete first round of this process. The final outcomes of the study will inform a number of acquisition projects and fleet sustainment systems within the Australian Army, as well as contributing to international collaborative work through The Technical Cooperation Program (TTCP).

2. The Motivation for a CBM Technology Impact Study

When attempting to anticipate the effects of new technological systems it is important to develop a consistent assessment framework, with a view of the systems as more than just technologies in themselves, but also as a way of doing things with associated practices, processes and policies. Quite frequently, factors other than inherent technological merits determine the success or failure of new technologies or technologies in new contexts [2]. The socio-technical context of the technologies [3], the interest groups, and the feasibility of complementary changes necessary for success [2] will affect the way that technology diffuses through society. Furthermore, these changes are not always technical, and may include habits, attitudes and ethical considerations [2].

In the assessment of consequences of technological changes, consideration should be given to the impact of the technological change on the operational environment [4]. Often the largest effects are not the direct ones, but are additive and multiplicative effects of practice replication and emulation, or further developments of associated technologies and formation of sustained behaviours [3]. It should be noted that futures research in technology assessments does not claim to produce completely accurate or comprehensive descriptions of future scenarios [3], but facilitates aspects such as:

- identification of technology outcomes and impacts over time [3], including social impacts [5]
- systematic identification of elements and linkages that cause program impacts [3]
- systematic analysis of programs and policy choices [3, 6]
- avoidance of pitfalls and maximising of opportunities [6]
- identification of areas of uncertainty and its implications [5].

There are multiple groups within various government departments in Australia and overseas that compile subject matter expert (SME) reports through 'technology watch' and 'horizon scanning' processes, often with semi-quantitative analysis using Technology Readiness Level [7] ratings. A brief description of work conducted by the North Atlantic Treaty Organisation (NATO), TTCP, and individual government groups is provided in [4, 6, 8]. The Future Technologies Analysis Unit within DSTO's former Defence Systems Analysis Division focused on analysing emerging technologies and their military implications [9]. Additionally, smaller task groups within various divisions engage in the assessment of emerging technological trends to varying degrees.

In order to address the adoption of CBM within the military Land domain we propose a new future technology assessment framework that draws upon the most relevant elements of the models and methods reviewed below. The intention is for the framework presented in this report to become a generic assessment framework that can be used in the assessment of the introduction of new technologies, and not be restricted to CBM or to the military Land domain.

3. Review of Technology Diffusion Concepts and Assessment Methods

This section provides a brief review of a number of pertinent technology diffusion concepts and assessment methods. Aspects have been extracted from each and incorporated into the conceptual model described in Section 5.

3.1 Technology Diffusion Concepts

Within the technology implementation literature, the term 'technology diffusion' is used to describe gradual spread of technology use and its adoption within the social sectors. Evaluation of technology impact is underpinned by the conceptual understanding of how technologies are developed, implemented and diffuse within organisations and society.

An important distinction is made in [10] between the organisational decision to implement a new system and its actual use post-adoption. The authors state that in a majority of cases, the functional potential of Information Technology applications is underutilised, with most users employing only a limited range of its features and using them at a very low level. Consequently, mandating implementation is not in itself sufficient to ensure effective system use [10].

Examination of information technology adoption literature suggests that technology use changes and evolves over time, with adaptations to both technology and work practices. Detailed reviews of technology adoption models and concepts can be found in [11-13]. Below is a brief, high-level overview of models with a particular relevance to the CBM Technology Impact study. These and other models of technology development and diffusion present different ways to focus on relevant information, with a modified model for technology assessment proposed later in the document.

3.1.1 Diffusion of Innovations Model

One of the most widely acknowledged works in this area is the Diffusion of Innovations model developed by Rogers [3, 14]. The model focuses on five key elements [3]:

1. **The diffusion process** occurs as the audiences become aware of the technology, gather and analyse relevant information, and make a decision to adopt the new technology, or otherwise. They may then make a decision to implement the technology, replicate it in other settings, continue use, and institute original and structural changes to sustain the use of the technology. The process of diffusion has been shown to follow an S-shape curve (see Figure 1), with small initial numbers of adopters, followed by a rapid increase in numbers that gradually stabilises over time.
2. **The socio-cultural environment** refers to the social, political, cultural and market contexts that can facilitate or hinder technology diffusion. This includes the key players and decision makers, their relationships, and the context within which they operate.

3. **Audience characteristics** may reflect characteristics of individuals or organisations, which may be classified as 'innovators', 'early adopters', 'early majority', 'late majority' and 'laggards'.
4. **Technology characteristics** that are most likely to affect its adoption include
    - relative advantage over current technology or alternative technologies in terms of cost, productivity, style, ease of use, and status-conferring properties
    - compatibility with the social, cultural and physical environment and requirement for modification of existing environment
    - complexity and perception of technology complexity
    - 'trialability' of the technology
    - observability of benefits.

    Another common way of describing a new technology is to classify it as evolutionary (incremental) or revolutionary (disruptive) [4]. The sources of disruption may be procedural, due to synergy between technologies, due to reduction in constraints, or due to the way technology is used [6].
5. **Communication mechanisms** used to disseminate information about the technology may include broadcast (one-to-many), or contagion (one-to-one) through networks, with varying degrees of effectiveness.

A graphical illustration of how these aspects might apply to a government-led technological program is provided by [3], reproduced in Figure 2. Particular consideration of the technology characteristics in point four above is central to our proposed model, as will be seen in Section 5.

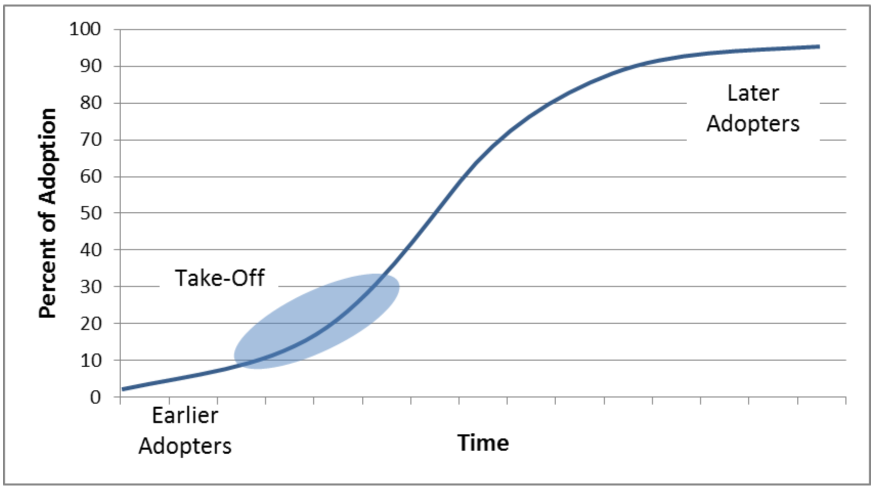


Figure 1: An illustration of the Diffusion of Innovations, adapted from [14].

Following on from the work of Rogers [14], various models have been proposed in the literature based on further studies. These include Technology Acceptance Model, Unified Theory of Acceptance and Use of Technology, Structuration Model of Technology,

Adaptive Structuration Theory, Model of Mutual Adaptation, Model of Technology Appropriation, Diffusion/Implementation Model, and Tri-core Model, among others [11].

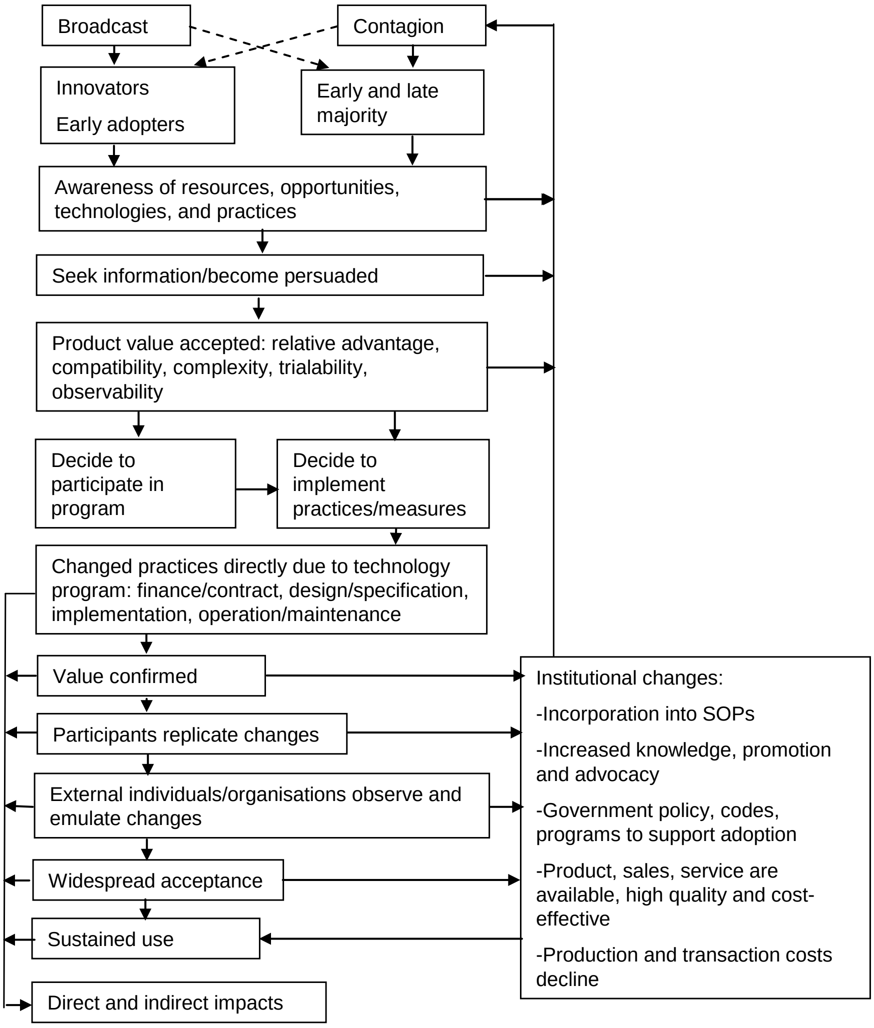


Figure 2: Adaptation of Diffusion of Innovations model for technology programs [3].

3.1.2 Analytical Framework for Evaluating the Impact of Technology on Future Contexts

When identifying current and emerging technology trends and their potential influence on the development of future warfighting concepts, Dortmans and Curtis [4] point out that this is not a simple process. They consider the interplay between:

- technology concepts (a technological view), arising from e.g. scientific discoveries, technological trends, or research and development innovations
- warfighting concepts (a military view), arising from e.g. strategic guidance, operational experience or military expertise

- changing contexts (a cultural view), arising from historical insights, sociological constructs, or cultural constraints.

The relationship between these views is illustrated in Figure 3. Each of the views is influenced by the others, e.g. technology concepts influencing, and being influenced by, military concepts through such mechanisms as battlespace effects, military applications and future needs [4]. We wish to incorporate all three views into our conceptual model, by incorporating a technological context and cultural context that defines the boundaries of our CBM Technology Impact study.

The authors of [4] further identify the notion that there is a progression from a scientific discovery through intermediate phases to usable military technology outputs and new warfighting concepts. Figure 4 reproduces the proposed formalisation of this progression from [4], including the stakeholder groups involved in the various phases. This conceptual model highlights the bidirectional nature of this progression, capturing both the 'technological push' and 'environmental pull' forces involved. For example, technological concepts may suggest military applications, but conversely military applications may identify technological concepts. As will be seen in Section 5 our conceptual model aims to capture aspects of the progression in Figure 4 from 'scientific disciplines and enabling technologies' (e.g. Health and Usage Monitoring Systems (HUMS), data processing, prognostic algorithms) all the way through to 'battlespace effects' (e.g. increased fleet effectiveness).

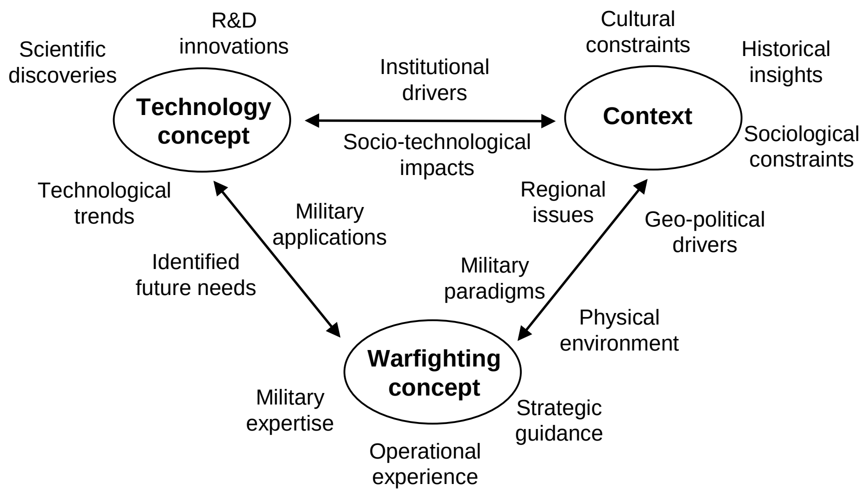


Figure 3: Interplay between technology concepts, cultural contexts and warfighting concepts [4].

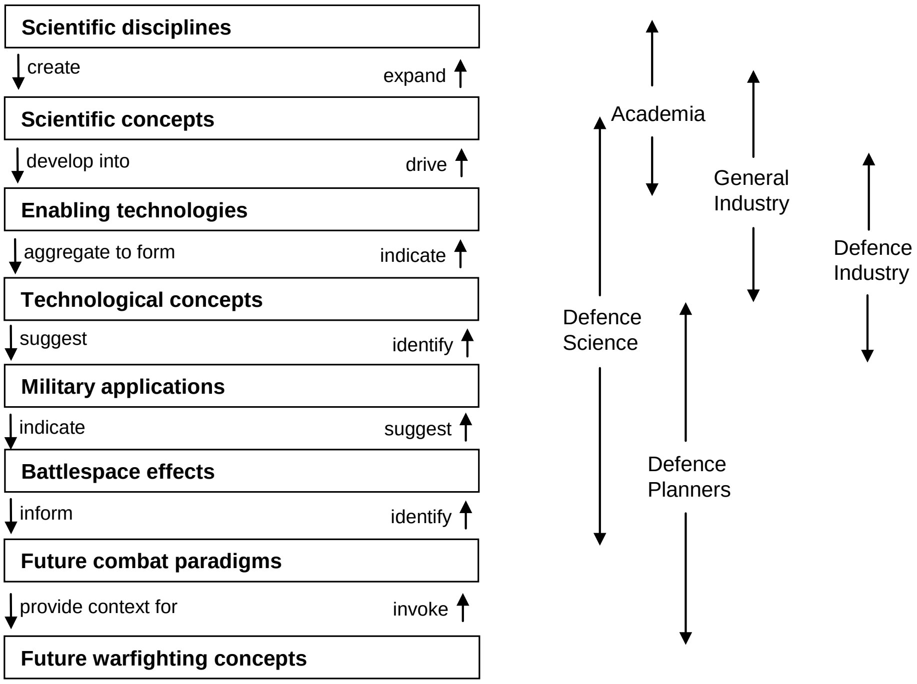


Figure 4: Linking science and technology developments with military applications [4].

3.1.3 Integrated Definition Function Modelling (IDEF0)

A function modelling method that has been widely adopted for military capabilities is Integrated Definition (Function Modelling) (IDEF0) [15, 16]. IDEF0 graphically represents functions and activities within an organisation and relationships between these activities, to produce outputs for customers. The key concept within the model is the transformation of Inputs into Outputs, limited by a set of Controls and enabled by a set of Mechanisms [17], as shown in Figure 5. The notion of transformation of inputs to outputs has been adopted in our proposed model.

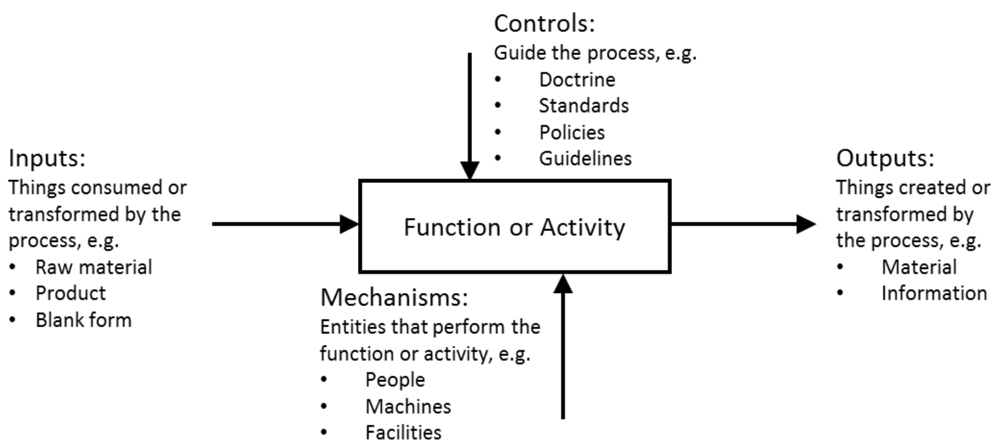


Figure 5: IDEF0 functional modelling [17].

3.1.4 Enhanced Model of Technology Appropriation

An enhanced version of the Model of Technology Appropriation [18] has been proposed by Fidock [11]. The model is based on the author's studies of information technology adoption within the Australian Defence Force (ADF) and is used as the primary basis of our conceptual framework in Section 5. It is represented graphically in Figure 6.

The author describes the process of appropriation as being characterised by progression through two phases: technology as initially encountered and technology in use. When the users first encounter technology, they conduct an initial evaluation and may perform initial adaptations of the technology. This results in the decision to adopt or not to adopt the technology. The second phase involves further evaluation and adaptations to both the technology and user practices. Ongoing evaluations may result in 'embedded appropriation' – technology being comprehensively incorporated within practices and being taken for granted as part of the users' work lives. Alternatively, partial appropriation may manifest in workarounds and minimisation of use, or the new technology may be rejected.

The author further points out that the process of appropriation affects, and is itself affected by, the users' beliefs and attitudes, and by personal, technical and organisational contexts. It is these aspects in particular that are the focus of our proposed model and study.

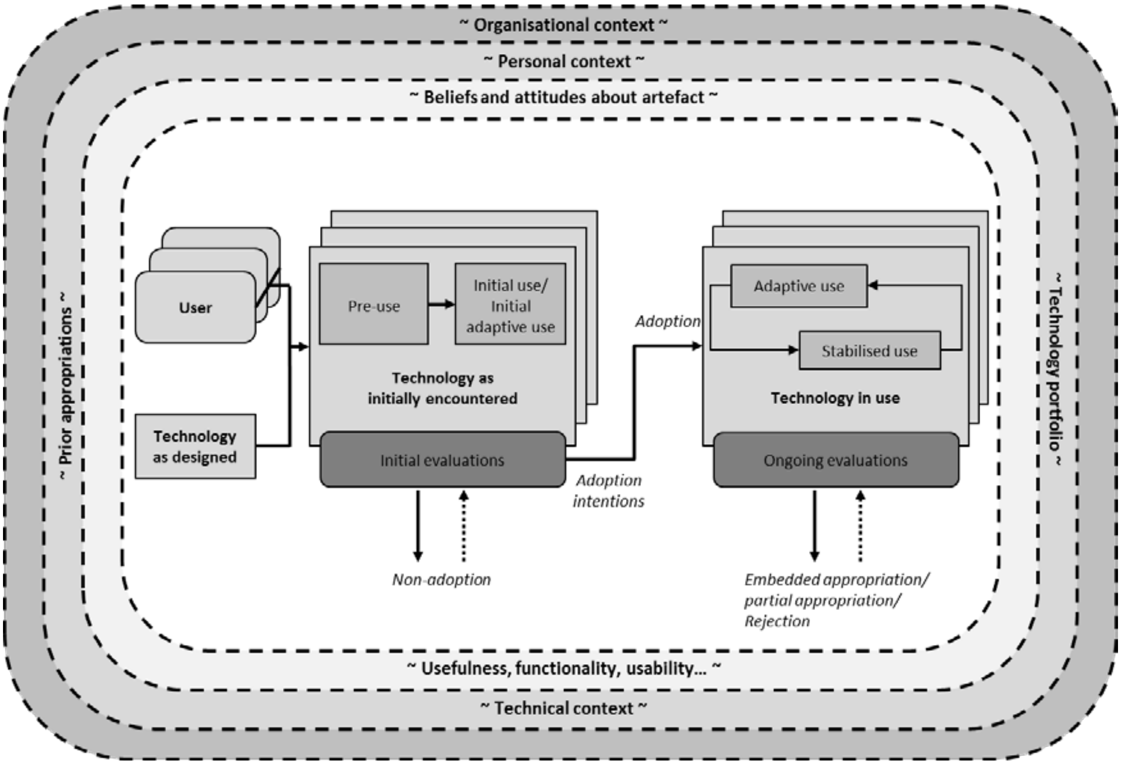


Figure 6: Modified model of technology adoption (adapted from [11]).

3.2 Technology Assessment Methods

Technology assessment has been a growing field over the last four decades [19] with variable terminology used to describe studies related to future technologies. For example, Future-oriented Technology Analysis can be used as a common term for technology foresight, technology forecasting and technology assessment [20]. Foresight definition developed by the High Level Group appointed by the European Commission refers to "a systematic, participatory, future intelligence gathering and medium-to-long-term vision-building process aimed at present-day decisions and mobilising joint action" [20]. Technology assessment can be defined as: determining the trend of technological change and their implications for the relevant social sectors; systematically evaluating its consequences and their probability, severity and distribution; attempting to forecast potential future trends and their consequences; and making decision recommendations so as to maximise desired benefits and minimise negative effects, in line with normative policies [5]. This latter description is implied in references to technology assessment, which is the focus of the CBM Technology Impact study (a technology-based approach to future studies).

Although various techniques have been developed to facilitate technology assessment, it is generally accepted that due to the breadth and variations in technology assessments, there isn't just one readily-replicable method [5, 21]. However, a methodological framework based on defined principles and models is both possible and necessary for a systematic approach to dealing with the complexity of the task and for dealing with associated uncertainties [3-5]. Desirable elements of a technology assessment are articulated in [5], reproduced in Appendix A.

A brief characterisation of technology assessment methods is given in Appendix B. We describe below the two methods most pertinent to our CBM Technology Impact study.

3.2.1 The Delphi Survey Process

Perhaps the most popular technique for collection and validation of information from SMEs based on published literature, previous studies, and consultation with SMEs within DSTO, is the Delphi survey process. Delphi was conceived by the RAND Corporation in 1940s and 1950s and has been used by the Japanese government to conduct foresight surveys since 1971 [8]. An overview of Delphi survey principles is provided by e.g. [22, 23]. In its simple form, the SMEs are asked to write down their responses to survey questions independently. These responses are then revealed (without identifying the respondents) and debated openly. The SMEs are then asked to provide their (potentially revised) responses again. The median of the responses is accepted as the group's decision [22, 23].

A Delphi-like approach has been adopted in our study through at least two rounds of survey, the first aimed at eliciting independent responses from SMEs and interested parties, and the second (and subsequent) aimed at achieving consensus on the information in those responses. Like [24, 25], we adopt an electronic means (email in our case) of conducting the surveys in a distributed fashion.

3.2.2 Benefits Analysis

Benefits Analysis has been developed for use in military operations research for the management of capability investment [26]. This method forms the basis of the proposed technology assessment framework described below. It focuses on analysing investment options on the basis of value, rather than immediate characteristics. It is based on creation of an acyclic (causal) benefits map representing the progressive effects of investments rather than the operational activities of the enterprise [26]. The end of the benefits chain is an expression of high-level values against which alternative investment options can be compared and contrasted. These benefits can then be evaluated against a corporate value system. Formal network analysis tools can be used to identify the potent nodes, powerful causes and common effects. Informal, expert inspection of the map can be used to draw out themes and strands for further analysis. This further work may relate to evaluation strategies using techniques such as matrix-based scoring, network-based functions, and strand-based multi-method evaluation [26].

Our proposed model is based on the creation of a causal 'impacts' map, similar to the benefits map described above, but where 'impacts' can be both positive (benefits) or negative (costs). Further, we do not restrict the map to being acyclic.

4. CBM Technology Impact Study Design

The following steps are proposed for the CBM Technology Impact study, based on a selection of the most relevant elements of the reviewed models and methods:

1. Undertake a survey of technology assessment methods and conceptual models based on published literature (Section 3) and consultation/workshop with SMEs in order to develop a conceptual model for this study (Section 5).
2. Establish contacts with SMEs in the relevant field, so as to secure their future participation in survey-based data collection and other future studies.
3. Establish study boundaries in relation to: time horizon, geographical scope, technology description and application, impact sectors, institutional and policy considerations, and study facilitator and participant considerations [5][1]. It is expected that this will involve consultation with relevant SMEs who can help shape the problem space.

---

[1] The following criteria are further suggested for use in setting the boundaries:

- system centrality (judgement about how critically the subsystem or relationship in question would impact or be impacted upon by the larger systems)
- resource limitations
- cognitive limitations in terms of availability of information, knowledge, understanding and proven methodologies
- political factors in terms of policy relevance and effects of political and economic factors within different boundary settings.

4. Perform environmental scanning of the current state of CBM in military systems via literature review, together with 'emerging issues' analysis considering pertinent trends, technology integration issues (including with emerging technologies), identification of stakeholders, refinement of boundaries, and recording of assumptions.
5. Construct the initial 'baseline' CBM Technology Impact model (the 'impact map') using information collected via the literature review and via workshopping with immediately available SMEs[2]. The initial CBM Technology Impact model is constructed based on a thematic analysis [27] of the collected information.
6. Validate the CBM impacts model, as well as assumptions and boundaries, via SME consultation using a semi-structured survey approach based on Delphi survey principles, with elements of self-appraisal incorporated into the process. This is to be done over two (or more) survey rounds [23, 24]. Responses to the more general questions of the first round will be subject to thematic analysis, which is, in turn, will be used to refine the previously constructed impact map. Significant changes will be identified and analysed. This model and its boundaries and assumptions will then be refined over the second and, if required, subsequent survey rounds[3].
7. Analyse the map based on identification of themes and strands within the model with discussion of pertinent considerations and areas of uncertainty.
8. Compile recommendations for further studies and trials.

5. Proposed Conceptual Model

The following 'impacts' model facilitates structuring and analysis of CBM-related information within the study. It is based on various elements of the models for technology diffusion [11-13] and futures studies on technology assessment [5, 19-21] described in Section 3. It is meant to act as a framework for structuring and validation of CBM-related information that can then be used for further analysis. It is built around the central process of Inputs (generating) → Capability (resulting in) → Outputs, and encompasses:

- consideration of the factors, particularly technology characteristics, from the Diffusion of Innovations model of Rogers [3, 14]

[2] While a more comprehensive workshop using SMEs from different locations would be desirable, it is unlikely that there will be resources available for this.

[3] Considerations in the design of surveys include the conflicting requirements of providing the respondents with some kind of reference framework in the first instance, but on the other hand, avoiding leading them in a particular direction and preserving divergence of views. It is intended that the first iteration of surveys is designed using open questions that structure the information within the required categories, but do not suggest the answers. In the second iteration, opinion can be sought about the picture formed from combined responses.

- consideration of the factors surrounding user beliefs and attitudes, and personal, technical and organisational contexts from the Model of Technology Appropriation [11, 18]
- the notion of Inputs being transformed into Outputs from IDEF0 modelling [15, 16]
- a mapping of 'impacts', adapted from Benefits Analysis [26], applied to both inputs and outputs.

A diagrammatic representation of our conceptual model is shown in Figure 7 and described below in conjunction with the corresponding details from the CBM Technology Impact study.

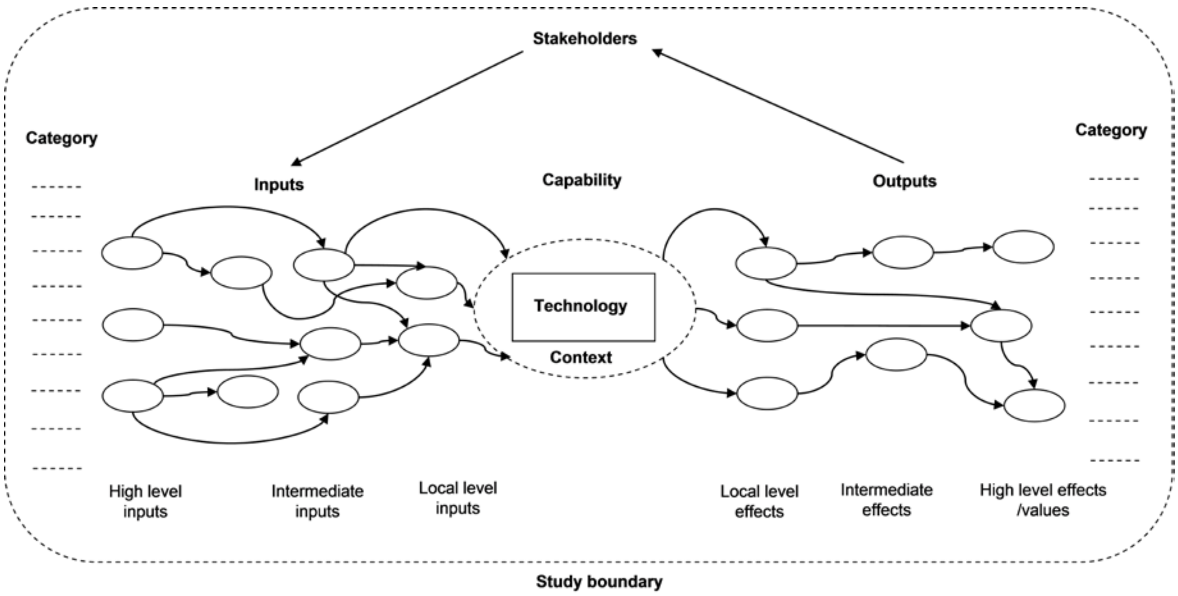


Figure 7: Proposed Impacts Model for the CBM Technology Impact Study

5.1 Elements of the Conceptual Model

5.1.1 Study Boundary

The selected boundaries for the study include the:

- expected application of the technology: primarily (but not limited to) military land vehicles
- time horizon: out to 20 years from now
- geographical scope: in barracks and on deployment
- impact sectors: covered in the Stakeholders section below
- range of policy options and constraints: includes such items as doctrine, land vehicle concept documents, legislation (Workplace Health and Safety,

maintenance, environment, data protection, auditability, accountability, operational security, storage of data, access to data, legal status of data).

5.1.2 Technology

Central to the model is the technology under consideration. This includes the following information: a description of the technology itself; a description of the normative boundaries selected for the study; and a description of technology characteristics that are likely to affect its implementation. The latter includes the technology characteristics from the Diffusion of Innovations model described above [3] and may include answers to questions from the following breakdown:

- Relative advantage
  - Does it cost more than the existing/alternative options?
  - Does it change other important resource costs (time, organisational attention, maintenance)?
  - Does it provide new/same/more functions than existing products?
  - Is the functionality desirable from user point of view?
  - Does it have desirable aesthetic qualities?
  - Does its use confer socially-valued status?
- compatibility with social, cultural and physical environment
  - Is it compatible with the system in which it's to be used?
  - Do the required complementary elements exist to support the product?
  - Do installers have to be trained to install it? Do they require special tools and equipment that they do not currently have?
  - Can it be installed or made to work under any condition or only under special conditions? Do these conditions occur frequently?
  - Do existing systems have to be modified to use it?
  - If it does not fit in an existing system, is a supporting system easy to create?
  - Are inputs required to make technology or practice work? Are they available?
- complexity
  - Is the function of the technology easy to understand?
  - Is it easy to install?
  - Is it easy to control?
  - Is the product intuitive and easy to learn to use?
- 'trialability'
  - Is it possible to borrow/buy one to try?

- Can the product be installed and used?
- Is it possible to have demonstrations that illustrate the effect of the product?

- observability of benefits
    - Is it possible to see the product working?
    - Is there a way to dramatically demonstrate what the product does?
    - Is it possible to touch, feel, hear or observe the results of using the product?
    - Can the results be measured and demonstrated?

Some of this information will be apparent from technical parameters, some from survey responses, and some from analysis of information from the rest of the model.

This study considers an instantiation of CBM technology in the military Land environment, covering data acquisition and collection, data transmission, data storage and warehousing, data processing and analysis, and maintenance decision support. We are also considering those aspects of HUMS technology that enable CBM, such as embedded sensors and built-in or portable diagnostic equipment. Integration with existing on-vehicle and enterprise systems, on-vehicle processing capabilities, data transmission bandwidth limitations, perceived complexity of the new technology and an ability to demonstrate benefits are all factors that are likely to affect the implementation of CBM.

5.1.3 Context

The context of technology implementation determines the significance or otherwise of the various factors that may influence technology use. These are likely to include the following aspects:

- technical environment: the current and emerging set of technologies with which CBM will need to interface and/or integrate, e.g. rapid development of computer and sensor technologies, reduction in hardware costs, advances in prognostic technologies
- military environment: strategic guidance, specific policies, budgetary constraints, and capability acquisition characteristics (see Appendix C), e.g. equipment usage profiles, non-uniformity of usage rates
- socio-cultural environment: characteristics of users at local, intermediate and high levels, their normative beliefs and their requirements, prior practice, culture and norms, e.g. current materiel maintenance practices, ‘spy-in-the-cab’ syndrome, perceptions of adding additional workload
- physical environment: physical parameters (temperature, humidity, noise, vibrations, dust, dirt, impact) and psychological parameters (operational tempo, level of threat, etc.) under which the technology will be utilized, e.g. training exercises, in barracks vs. on deployment, peacetime vs at war will be considered.

5.1.4 Inputs, Outputs and Categories

When attempting to determine the value proposition of a new technological system, inputs in terms of resources, policies and processes can be used to determine the various costs associated with the capability. The proposed model is designed to develop a progressive picture of inputs required for the technology system to be implemented and used effectively, following a reverse causal-map sequence. The input list is built up by following from the question: 'What are the immediate elements required to make the system work at the local level?' and then following through with the same question for each identified element. A forward pass through the map can be used to ensure completeness and consistency[4].

Outputs, on the other hand, can be used to capture benefits, neutral effects and risks associated with the capability. The outputs picture is built up by asking the question 'What are the local-level effects of using the technology?' and then building up the nodes by asking the same question about the generated outputs. It follows forward-pass process first, with backward pass used for completeness and consistency.

While the Benefits Analysis method [26] recommends the use of acyclic causal maps for capturing inputs and outputs in order to reduce complexity, we have not enforced this restriction. This allows for the capturing of cycles such as feedback loops and iterative impacts within the map.

It should be noted that there is a significant judgement-based component in selecting particular impacts as more significant than others, aggregating similar impacts, and leaving others out in order to manage complexity. This is expected to be somewhat alleviated by following a rigorous process of tracking the information through published references and via validation by SMEs.

Further coding of both inputs and outputs on the map (using colours, shapes, and dashed lines) may be used to highlight particular characteristics of inputs and outputs. The types of characteristics that may be of interest in this case include:

- temporal characteristics (short-term, medium-term, long-term)
- directness (primary, secondary, tertiary/indirect, integration effects)
- desirability (positive, negative, neutral, unknown, mixed)
- type (Fundamental Inputs to Capability (FIC)[5] categories)

[4] When considering inputs within the decision-support framework, it is important to distinguish between minor and major capital investments that are required additionally to those that already exist, as well as whether these are optional.

[5] The FIC categories describe inputs considered fundamental to the development and delivery of military capability and comprise Command and Management; Organisation; Major Systems; Personnel; Supplies; Support; Facilities; and Collective Training. They are similar in nature to the US DOTLMPF categories (Doctrine, Organisation, Training, Materiel, Leadership, Personnel, Facilities), the UK MOD TEPIDOIL categories (Training, Equipment, Personnel, Information, Concepts and Doctrine, Organisation, Infrastructure and Logistics), and the Canadian PRICIE

- strength of evidence (level of support in the literature and from SMEs).

It is anticipated that the high level inputs will be derived from a set of categories such as FIC, and likewise that the high level effects will feed into similar categories. This is captured on the left and right of Figure 7. A description and brief discussion of the identified inputs and outputs is given in Section 6.

5.1.5 Stakeholders

Examination of stakeholders who have to generate the capability inputs and/or are affected by the outputs can be conducted to various levels of detail, depending on the available time and on the significance of the information to the overall study. At a simpler level, this part of the analysis can be performed after most of the inputs and outputs have been identified and prioritised. The more significant inputs and outputs can then be selected and analysed in terms of their specific effects on the interest/stakeholder groups.

There are various suggestions for grouping stakeholders in the literature [3, 4, 28]. Our study has identified the following high-level stakeholder groupings, with examples of stakeholders from an Australian Defence context:

- materiel suppliers
  - Original Equipment Manufacturers (OEMs), Defence contractors
- capability development/acquisition organisations
  - Capability Development Group (CDG), Defence Materiel Organisation (DMO), DSTO, OEMs, Engineers
- research and academic organisations
  - DSTO, universities
- security organisations (both within and external to Defence)
  - within Defence (e.g. Australian Signals Directorate (ASD), Defence Intelligence Organisation (DIO))
  - external to Defence (e.g. OEMs, Defence contractors)
- End-users
  - equipment operators, crew, passengers
- planning and management
  - fleet managers (e.g. Defence Materiel Organisation (DMO) through System Program Offices (SPOs), Forces Command (FORCOMD), OEMs, Defence contractors), Operational planners, Strategic planners, Information and Communication Technology (ICT) managers
- legal and doctrinal

categories (Personnel, Research and development, Infrastructure and organisation, Concepts, doctrine and collective training, Information management, Equipment and material).

  - ADF policy-makers (e.g. Army Headquarters (AHQ)), legal personnel, accident/incident investigators, legislative bodies external to Defence
- IT and support
  - logistics personnel, Information technology (IT)/signals personnel, data analysts, training personnel, supply personnel (e.g. supply chain personnel)
- maintenance personnel
  - maintainers, maintenance planners, recovery personnel, workshop managers, equipment/maintenance SMEs, OEMs, defence contractors (e.g. for heavy-grade, 4th Line, National Support Base, or contracted support);
- adversaries
  - enemy forces, external commercial organisations (i.e. not engaged by Defence)
- miscellaneous:
  - Australian public, ADF as a public entity.

5.2 Information Capture Process

In addition to the five characteristics (temporal, directness, desirability, FIC categories, and strength of evidence) mentioned above, we are attempting to capture the following information for each impact:

- description: a description of the impact
- reference: where the impact originated (specific item(s) of literature, SMEs)
- generated/caused by: which other impacts generate or cause this one
- generates/causes: which other impacts are facilitated by this one
- affected groups/stakeholders: which groups or stakeholders are affected by this impact
- assumptions: any assumptions relevant to the manifestation of this impact
- boundary decisions: decisions about what aspects of an impact are within the scope of the study.

This approach is designed to ensure that information, arguments and linkages can be tracked and are auditable. It may also facilitate some degree of automated data analysis in the future.

5.3 Data Analysis

Construction of the impact map facilitates different types of data analysis. Formal network analysis techniques can be used to identify potent nodes, powerful causes, and common

effects [26]. A more informal expert evaluation can be used to identify themes and strands within the map. Themes are generally used to check for completeness and consistency of the map. Strands form distinct threads of the overall business case for the investment option [26]. Expanding such strands using a backward pass through the map will further allow identification of what else can produce similar benefits (i.e. alternative investment options). However, it is likely that the outputs of this initial study will be limited to the identification of the more significant technology impacts and key trends, with specific recommendations for further work.

6. Input and Output Impact Maps

The following progress has been made on the CBM Technology Impact study:

- Potential SMEs, stakeholders and interested parties from within DSTO, within the Australian Defence Organisation, and through TTCP Land Group Action Group 5 (LND AG-5) 'Land Force Logistics' connections, were contacted to assess their level of interest in participation in this study.
- A 'baseline' CBM Technology Impact map has been established, from sources in the published literature and from an internal DSTO workshop.
- A 'First Round' of surveys was sent out to those parties who previously indicated their interest. The responses received were made anonymous and collated.
- Modification and augmentation of the baseline impact map to incorporate First Round survey responses has been completed. Creation of the so-called 'First Round Impact Map' has involved
    - adding nodes (impacts) and causal links between nodes to the map as intimated from survey responses
    - marking relevant nodes as having support from the SME/stakeholder community from the First Round survey, hence identifying areas of importance to this stakeholder community
    - identifying conflicting survey responses
- A Second Round survey has been designed and distributed to participants. This survey asked participants to examine the impact map and provide feedback on its structure and content, including comments on their perception of the least/most critical impacts and their opinions on the conflicting responses previously identified.

This covers steps 1 to 5 of the study design described in Section 4, with one survey round from step 6 also completed.

6.1 Creation of the Baseline Impact Map

Many potential impacts of CBM, both those required to establish CBM (input impacts) and those flowing from adoption of CBM (output impacts), were identified from the literature and from an internal DSTO workshop. Creation of the baseline impact map from this information was undertaken in three steps.

The first step in creation of the baseline map was to introduce some order into the collection of impacts by applying thematic analysis [27]. A thematic coding was applied to the impacts, initially to identify the broad category area to which each impact belonged. As an example, some of the codes used included 'acquisition', 'change management' and 'data management'. These codes formed the basis of the themes under which 'like' impacts were collected. As per [24], this allowed for a standardisation of language, and for duplicate impacts to be identified and removed. Unlike [24], however, we recorded the number of times a particular impact appeared, in order to provide an indication of 'strength of evidence' from the literature.

Subsequent to this initial thematic analysis, as a second step, additional coding was applied to the de-duplicated impacts relating to the properties identified in Section 5.2. However, these codes were not used for further thematic analysis.

Finally, as part of the internal DSTO workshop, causal links between impacts were identified by workshop participants. This provided a starting-point for the establishment of causality between impacts, to be built upon by participants in the first and second-round surveys.

6.2 Creation of the First Round Impact Map

Following collection of responses to the First Round survey, we undertook a process to refine the baseline impact map to produce a 'First Round' impact map. In a similar way to that described in [24], thematic analysis was used following the first round of surveys to integrate the responses into the baseline map. A three-step process was used.

The first step was to extract the impacts from each survey response and apply a similar coding to that applied when the baseline map was developed. The number of survey respondents that mentioned a particular impact was recorded prior to de-duplication, to provide a corresponding measure of 'strength of evidence' from survey respondents to compare with that of the literature.

The second step involved comparing the themes and impacts to those already present in the baseline impact map, and adding themes (clusters) and impacts as required. This resulted in a new cluster and numerous new impacts being added to the map. In a number of cases (described in Section 6.3.2) survey respondents provided conflicting opinions, or were in conflict with impacts identified in the literature. The corresponding impacts were flagged as such. No attempt was made by the facilitators to de-conflict these conflicts; rather these conflicts formed the basis for part of the Second Round survey.

Finally, additions and modifications to the causal relationships between impacts suggested by the survey respondents were implemented.

6.3 Depiction of the First Round Impact Map

Graphical representations of the input and output portions of the First Round Impact Map are shown in Figure 8 and Figure 9 respectively, with the following properties:

- impacts have been grouped into clusters based on the key themes identified
- each impact is labelled by the number of the cluster to which it belongs and a letter for uniqueness within the cluster
- each impact has been annotated with the 'strength of evidence' scores described previously, where the scores in the red and blue circles correspond to the citation counts for literature and survey respondents respectively
- within each cluster the impacts with the highest weight of evidence from literature and from survey responses have been highlighted with blue or red borders, respectively
- impacts indicating a conflict of opinion are highlighted with two scores within orange circles, representing the level of support for each of the opposing opinions
- causal links between impacts are indicated by arrows
- red text indicates additions or modifications to the baseline impact map (a new cluster and new/modified impacts) as a result of First Round survey responses.

A graphical representation of stakeholders, directness, desirability and temporal characteristics has not been shown on the map, but are presented in a spreadsheet format in Appendix D.

6.3.1 Input Impacts

The input impacts have been arranged into seven clusters, representing seven key themes identified during the thematic analysis:

1. Leadership at a High Level and a Local Level
2. Incorporation of CBM Requirements into the Capability Acquisition Process
3. Change Management
4. Acquisition or Modification of HUMS-enabled Equipment/Platforms
5. Data Management Strategy
6. Training and Personnel Certification
7. Technology Integration.

A detailed breakdown of the clusters into individual impacts is given in Figure 8. For the input impacts, we have considered cluster headings to be impacts in their own right, based on survey responses that mentioned the theme in general terms but without specifics.

From this figure we see that there is a reasonable spread of support from survey respondents across the seven clusters. Impacts relating to data management and technology integration are also well supported by the literature. However, the issues of incorporation of CBM requirements into the capability acquisition process and change management are almost exclusively mentioned by survey respondents only.

The eight most cited input impacts, based on either the highest blue, red, or highest total score (within each cluster), are given below, with the total score shown in brackets:

- **4a.** Acquisition of HUMS[6]/CBM hardware and software (15)
- **3a.** Development of new logistics and maintenance structures and processes (14)
- **6.** Training and personnel certification (14)
- **7b.** Integration of HUMS/CBM hardware, software and platforms (12)
- **4b.** Design of HUMS/CBM hardware and software maintenance (10)
- **5g.** Data mining, analysis and use for decision-support (8)
- **5h.** Development of algorithms (prognostics and diagnostics) (8)
- **2f.** Inclusion of CBM requirements into acquisition of relevant equipment/ platforms (3).

Excluding cluster headings, the nine least cited input impacts, with one citation each, are:

- **2c.** Allocation of ownership and management responsibility
- **2d.** Assessment of CBM solutions early in the design stage
- **2h.** Development of a business case for CBM
- **3b.** Allocation of resources for implementation and facility upgrades
- **3c.** Promotion of benefits
- **3e.** Amendment of existing maintenance contracts with civilian agencies
- **4e.** Increased modularity of equipment/platform design
- **5a.** Data architecture and standards
- **6a.** Modification of maintenance training facilities.

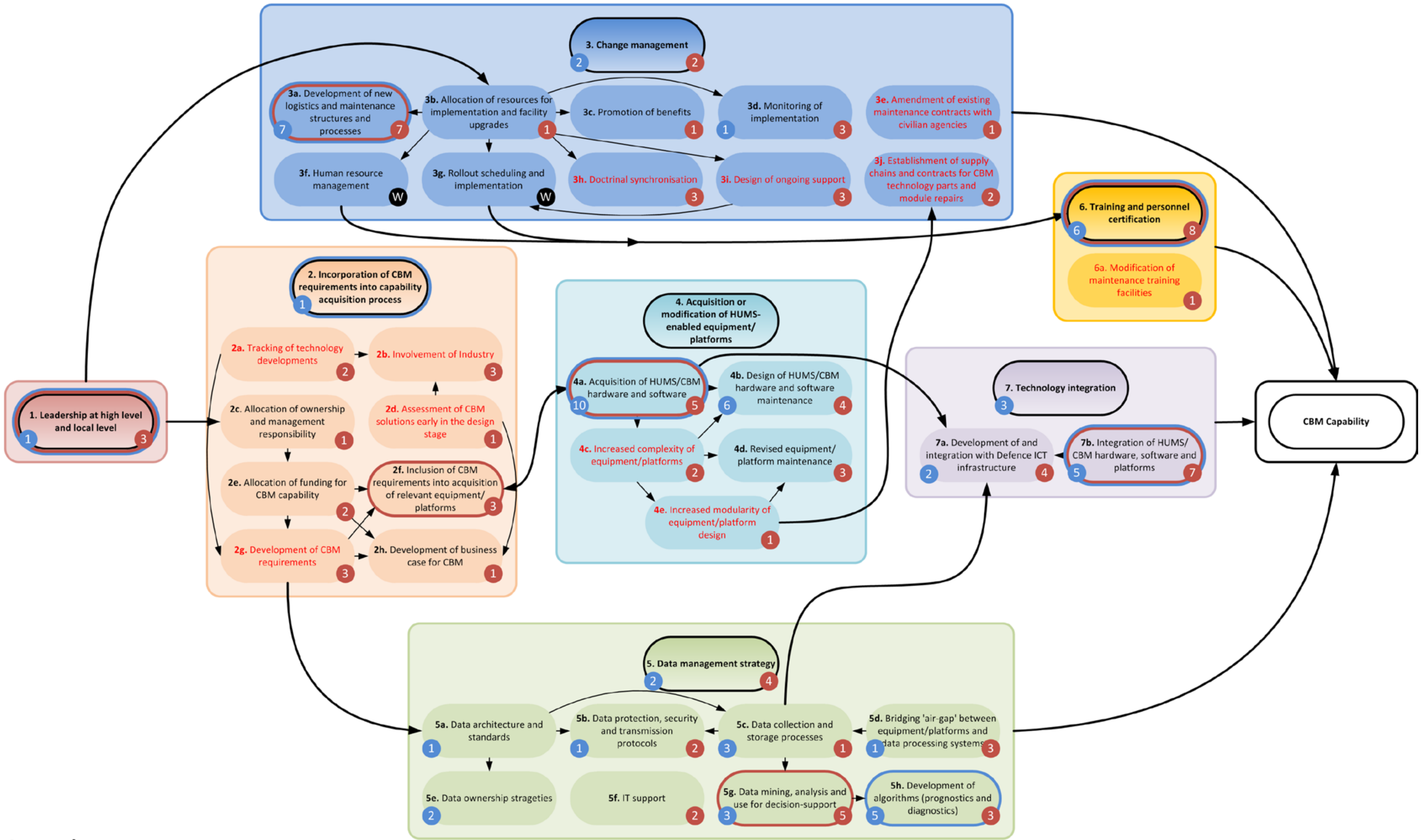
The Second Round survey will attempt to elicit consensus on the relative importance of these highest and lowest cited impacts.

[6] Health and Usage Monitoring System

Further, there were two impacts that were identified by an internal DSTO workshop that were not mentioned in literature or by survey respondents:

- **3f.** Human resource management
- **3g.** Rollout scheduling and implementation.

These have been labelled by a black circle containing the letter 'W' (for 'workshop'). We will be seeking the thoughts of participants on the importance of these impacts in the Second Round survey.



Legend:

Text:		Outlines:		Markers:		Arcs:	
Black text:	Impact identified from literature/internal DSTO workshop	Black outline:	Cluster heading	X	Number of items in the literature that identified this impact	→ :	Inter-cluster causal relationship
Bold text:	Cluster heading/high level impact	Blue outline:	Top-ranked impact based on literature	Y	Number of survey respondents that identified this impact	→ :	Intra-cluster causal relationship
Red text:	New impact/cluster heading identified from Round One Survey responses	Red outline:	Top-ranked impact based on Round One survey responses	W	An impact that was identified through an internal DSTO workshop but without support in the literature or Round One survey responses		

Figure 8: The Input Impacts portion of the First Round Impact Map

6.3.2 Output Impacts

In a similar way to the input impacts, the output impacts have been arranged into 12 clusters corresponding to the key themes identified:

1. Immediate Functions
2. Effects on Equipment/Platform, and of Integration with Other Technologies
3. Effects on the Workforce and Workforce Skill Base
4. Immediate Maintenance Effects
5. Resource Consumption Effects
6. Data Collection and Analysis Effects
7. Data Transmission Effects
8. Changes in Logistic Processes
9. Longer-term Maintenance Effects
10. Equipment/Platform Availability Effects
11. Impact on Mission Effectiveness.

'Resource Consumption Effects' was a new theme that emerged following the First Round survey that was not originally present in the baseline impact map. A detailed breakdown of the clusters into individual impacts is given in Figure 9. For the output impacts, cluster headings are not impacts in themselves, but rather were chosen as separate high-level descriptions of the clusters.

There can again be seen a reasonable spread of support for impacts in each cluster, with two notable curiosities:

- the majority of support for impacts to the workforce have come from survey respondents
- the majority of support for impacts relating to human factor effects have come from the literature.

Of the three promises of CBM (extend the useful life and reduce the through-life cost of equipment, improve fleet operational availability and combat effectiveness, and reduce maintenance burden) an 'increase in operational availability of equipment/platforms' (impact 10f) was the most cited impact in the literature, and was also strongly supported by survey respondents. Both the 'increased/more predictable equipment life' (impact 10g) and 'reduced overall maintenance burden' (impact 9e) received moderate support from literature and survey respondents.

The eight most cited output impacts are:

- **10f**. Increase in operational availability and capability of equipment/platforms (24)

- **9a.** Improved ability to plan maintenance, e.g. schedule maintenance in a load-balancing way (16)
- **12b.** Improved decision support for mission assignment of equipment/platforms (15)
- **10a.** Improved safety in operation of equipment/platforms (14)
- **8c.** Reduced inventory holdings at supply chain nodes (12)
- **1a.** Diagnostics (11);
- **8b.** More efficient and responsive supply processes (11)
- **9d.** Improved operation and maintenance of the fleet (11).

The lowest cited impacts, with a score of one, are:

- **2b.** Tracking of position, status and load of vehicles, critical stores and drivers
- **3e.** Increased demand for IT Support personnel
- **3f.** Increase in personnel capable of implementing and upgrading CBM systems
- **3h.** Decrease the skill/technology gap between Defence and civilian agencies
- **3i.** Reduced scope for innovative operator repair for platform 'revival' to complete a mission
- **3j.** Increased non-technical maintenance role for operators, cf. increased modularity
- **6e.** Improved data availability for accident/incident investigation
- **6h.** Improved monitoring of environmental pollution effects
- **6i.** Greater availability of terrain and environmental data
- **7c.** Increased ability of unauthorised external parties to access generated data
- **7f.** Increase in data security management requirements
- **8d.** Increased Information and Communication Technology (ICT) in workshops
- **8i.** Negligible impact on supply chain costs
- **8o.** Management of CBM components within the supply chain
- **9h.** Reduction in support equipment in the field and specialised support equipment at the Strategic level
- **9i.** Redesign of maintenance workshops with technical repair/refurbishment pushed rearward
- **9j.** Better utilisation of tradespeople, particularly for preventive maintenance
- **10i.** More difficult to obtain parts and technical knowledge as fleets age
- **10j.** Increased equipment down-time due to spare part obsolescence as fleet life is extended

- **11d.** Reduced accuracy of information underpinning decision-support
- **11e.** Cultivation of culture of equipment ownership/excellence.

As with the input impacts, the Second Round survey will attempt to elicit consensus on the relative importance of these highest and lowest cited impacts.

Further, four conflicts of opinion were discovered from the First Round survey responses, three of which come from Cluster 3:

- **3a.** Reduced vs. increased maintenance training requirements
- **3b.** Reduction vs. no reduction in traditional diagnostic and maintenance skills
- **3g.** Potential reduction vs. unlikely reduction in the number of maintainers
- **4b.** Less regular, more proactive maintenance vs. no decrease in regular maintenance.

It was also identified that impact 8i (negligible impact on supply chain costs) is at odds with the sentiments expressed by impacts 8c, 8h, 8b and 8n (reduced inventory holdings at supply chain nodes, reduced logistic footprint, more efficient and responsive supply chain processes, and better supply planning, respectively).

Opinions on this discrepancy and these conflicts of opinion will be sought from survey participants in the Second Round survey.

6.4 Preliminary Examination of Second Round Survey Responses

Based on a preliminary scan of Second Round survey responses, there will be significant changes to the structuring of the impacts, including the clustering of impacts, aggregation of 'like' impacts, dis-aggregation of impacts that are 'not like enough', and causal links between impacts.

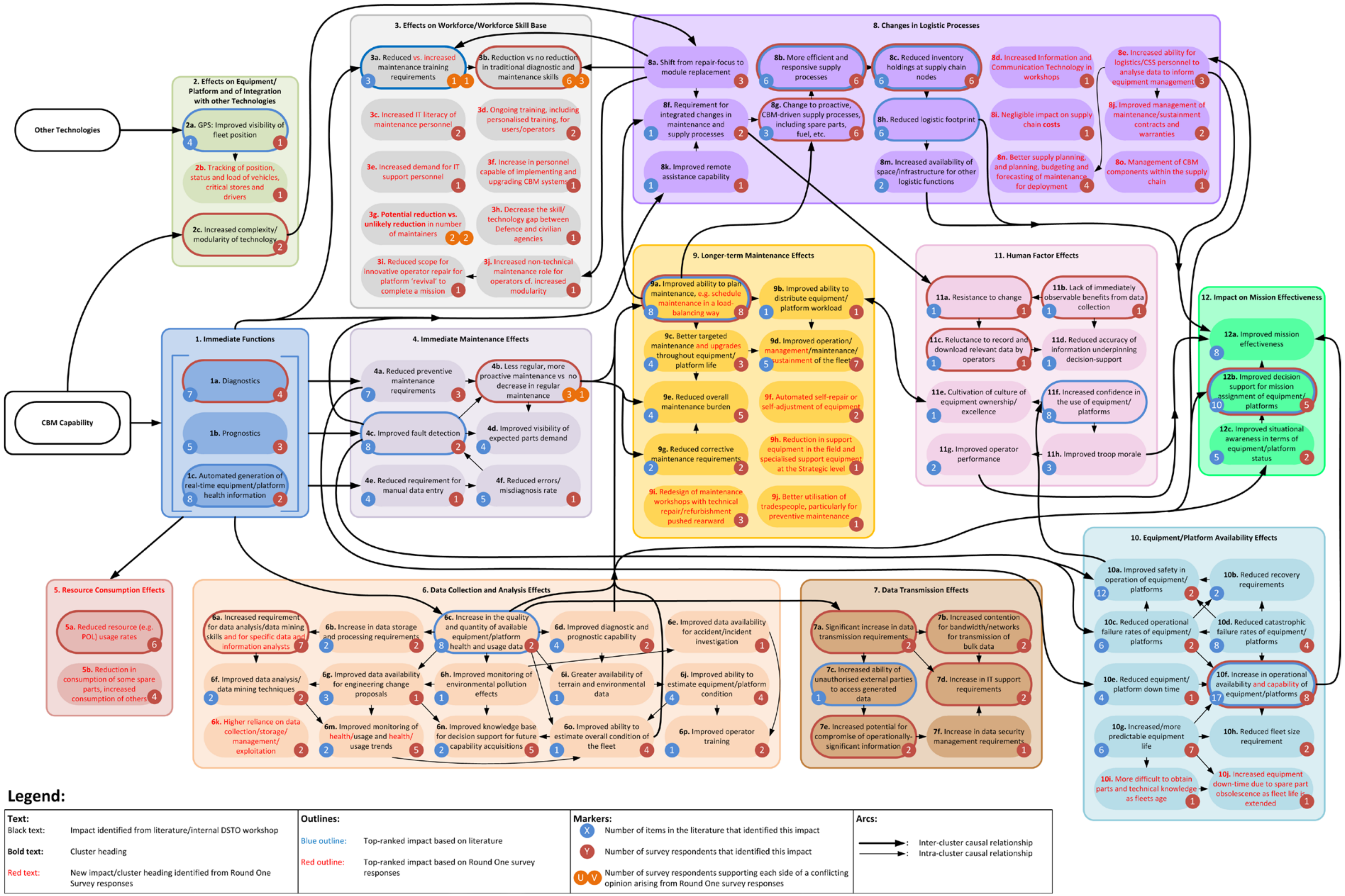


Figure 9: The Output Impacts portion of the First Round Impact Map

7. Discussion and Conclusions

This report has presented a new conceptual model for assessing the impact of adopting new technologies and our initial results from applying this model to conduct a Technology Impact study on the adoption of CBM in the Land domain.

7.1 Assessment of the Proposed Conceptual Model

The conceptual model developed for the CBM Technology Impact study has the following advantages:

- the structure allows for translation into further quantitative simulation models without significant changes in the conceptual approach
- it allows for consideration of multiple dimensions/characteristics of technology effects without an unnecessary increase in the complexity of the map itself
- it is based on consistent and doctrine-based categories (such as FIC)
- it allows identification of costs, benefits and risks of both an economic and non-economic nature that can be further used to
    - compare capability options
    - conduct further quantitative modelling focusing on specific aspects of interest (such as economic costs and benefits)
    - conduct detailed risk assessments
    - conduct change management studies.

It is likely that economic considerations will be a significant factor in any future capability investment decisions. The outlined conceptual model can be used to develop systematic lists of the expected economic costs (associated with the required inputs) and benefits (that flow out of the identified outputs). Further research and modelling would be required to actually assign dollar amounts to the items on these lists.

7.2 Uncertainty and Subjectivity in Futures Studies

As can be expected, studies that attempt to forecast and assess future conditions face greater challenges in terms of uncertainty than those focusing on present and past states. The sources of uncertainty for technology evaluations may be due to:

- the learning process that occurs with new technologies, whereby problems are identified and overcome and improvements are implemented [2]
- far-reaching consequences of small changes and improvements [2]
- political and social factors and budget constraints [2]

- difficulty in predicting technology integration and future uses [4]
- general reduction in the accuracy of predictions with increases in forecasting time [6]
- subjectivity in classification of effects as positive, negative or neutral [26]
- indirectness of cause and effect chains and difficulty in measuring complex effects produced by military action [26].

It is expected that a systematic approach to technology assessment will help identify areas of uncertainty and their causes. Some of these may be addressed in follow-up studies and trials, whereas some may have to be managed as risks.

Apart from the issue of uncertainties, it should be noted that this type of analysis inevitably contains elements that are normative, judgement-based, creative and subjective [5]. While quantitative methods may be relevant to some parts of the assessment, their use does not in itself add objectivity to subjective judgements or increase the rigor of a study based on subjective judgements [5]. Some of the normative issues [5] include

- choice of area and setting of boundaries for the study
- nature of questions for investigation
- choice of impacts, actors, and affected groups that are to be examined
- evaluation of impacts as adverse or beneficial
- identification of social groups that will experience these impacts
- decision criteria used in aggregating findings, and expressing judgements regarding uncertainty and risk
- policy issues reflected in the recommendations.

It has also been found that over-optimism in future estimates is quite common, especially for top experts [8]. It has been proposed that short-range forecasts tend to be optimistic and long-range forecasts pessimistic. This may be due to the fact that in the short-term, the technological solution is obvious, but the difficulties of system synthesis and implementation are underestimated; whereas in the long-term, no solution is apparent [8].

Gordon and Helmer [29] conducted a critical appraisal of a questionnaire-based method (such as Delphi) for future estimates and provided the following recommendations for dealing with the eight common criticisms presented in Table 1. For the CBM Impacts study, all recommendations to the eight criticisms have been adopted, with two exceptions:

1. Item 3, indicating that the time lapse between survey rounds should be kept to less than one month, has proved to be unattainable. It has taken time to analyse, assimilate and incorporate First Round responses in order to develop the Second Round questions. However, the two primary causes of slippage have been that some SMEs that previously indicated a willingness to participate either not responding or taking longer than anticipated to respond, and the propagation of

the First Round survey to additional participants identified by existing participants. We considered that any delays caused by the latter were offset by the benefits of additional participation.

2. Item 5 states several recommendations, of which the first three have been formally adopted, while the fourth has been adopted to some extent by encouraging participants to indicate their professional areas of expertise and depth of experience in CBM and related areas.

Table 1: Recommendations for dealing with common criticisms of the questionnaire-based future estimates methods [29].

Criticism of method	Recommendations
1. Future estimates are inherently unreliable and it is impossible to predict the unexpected.	The merits of the approach should be judged in terms of the available alternatives. Whilst no claims can be made for reliability of the predictions, this method is based on explicit, reasoned, self-aware opinions, expressed in the light of opinions of associate experts. This forms a better basis for long-range decision-making compared with purely implicit, unarticulated, intuitive judgements.
2. Instability of panel membership may impede convergence of opinions.	It is recommended that SME panel membership is kept as constant as possible throughout the successive rounds.
3. Large time lapse between successive rounds can reduce the quality of responses.	It is advised that time lapse between rounds is kept to less than one month.
4. Ambiguous questions can result in different interpretations from SMEs.	Question formulation should be kept as specific as possible.
5. Respondents' competence in particular areas affects the reliability of their estimates.	Several recommendations are provided to address this point: • improvements in systematic selection of experts • confining the questions to the respondents' areas of expertise • encouraging the respondents to leave blanks in questions if unsure • use of self-appraisal system for assessing the respondents' competence in answering each question • improving reliability of forecasts via use of suitable consensus formulae, possibly based on the appropriate self-ratings.
6. Self-fulfilling and self-defeating prophecies can occur following publishing of results.	It is expected that study results would be used to inform (and therefore influence) the decision-making process. However, one should be cognisant of the possibilities of political and ethical biases in responses, with certain differences between what the respondents may believe to be true, and what they believe to be right.
7. Consensus by undue averaging may occur with the standard Delphi approach which uses the median as a descriptor of the group opinion and the quartile range as a measure of the degree of consensus; this introduces undue bias against far-out predictors.	The respondent who disagrees with the majority opinion can be invited to state his/her reasons, so that all members of the panel have an opportunity to assess these and re-evaluate their opinions. Use of additional rounds can help consistently elicit reasons for minority opinions and provide opportunity for explicit critique of such reasons. Furthermore, development of techniques for formulation of sequential questions that would probe more systematically into the underlying reasons for the respondents' opinions, would allow development of understanding of the theoretical foundation of the phenomenon in question.
8. Achieving substantive breadth of enquiry is often constrained by the available time and resources.	Effort should be made to achieve adequate breadth of enquiry so as to explore the topic in sufficient detail, including related areas.

7.3 CBM Technology Impact Study Ongoing and Future Tasks

To complete the study, we propose the following remaining tasks:

- collection, collation and analysis of Second Round survey responses, which may include
  - achieve a consensus where possible on the relative importance of the impacts identified in the baseline map and following the First Round survey
  - extraction of economic considerations – an Economic Matrix, or 'money map'
  - breakdown and trending of results by timeframe, desirability or other characteristics
  - identification of 'negatives' in order to highlight possible risks associated with CBM adoption
- discussion of the validity of the results, which may include
  - assumptions, risks, and sources of bias
  - uncertainty associated with study outcomes, including knowledge gaps, indirect technology impacts and long-term impacts
  - strength of evidence, including open literature vs. survey responses
  - trends among stakeholder groups, including agreements and disagreements, and identification of the reasons why
- recommendations and identification of future work areas.

The authors are aware of the potential dangers related to forming 'rankings' of input and output impacts based on a small number of responses. Hence, we consider the attribution of the scores described in Section 6 as an indication of the issues that are perceived as important amongst the participating stakeholder groups. Time permitting, it would be desirable to conduct a SME workshop to validate the final impact map, along with SME validation of the characterisations of each impact listed in Appendix D (temporal, directness, desirability, FIC categories). However the feasibility of holding such a workshop remains to be determined.

Following on from the impacts study, it is our intention to use the results and insights gained to develop a 'value proposition framework' for CBM within the Land domain. Such a framework will take into account the quantitative economic factors behind both the positive and negative impacts, as well as the qualitative factors that may influence the decision to adopt CBM. Our intention is for the value proposition framework to facilitate 'what-if' analysis of CBM capability options to help decision-makers determine whether to adopt, and to what extent to adopt, CBM within the Land domain.

8. Acknowledgements

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Appendix A. Desirable Characteristics of Technology Assessment Methods

From [5], desirable elements of a technology assessment include:

1. statement of the problem under consideration
2. definition of the technological system and specific micro-alternatives for achieving the same objective
3. identification of the potential impacts of the technology
4. evaluation of potential impacts
5. definition of the relevant decision-making organisations
6. presentation of options to the decision-maker
7. identification of the parties of interest (winners, losers, overt/latent interests)
8. definition of broader system alternatives ('macro-alternatives')
9. identification of exogenous variables that may influence the system
10. conclusions and recommendations.

At this stage, our study is focused primarily on points 1 to 4 (along with point 10) but also touches on the other points to varying degrees.

Appendix B. Overview of Methods for Technology Assessment

The use of methods in combination can facilitate efficiency and robustness of the forecasting process [6]. A chronological overview of methods and tools for technology assessment is provided by Tran and Daim [19], with further description of various approaches in [21]. Various methods used for technology assessment are outlined in [20]. These can be grouped according to the characteristics of expertise, creativity, interaction and evidence (Popper's Diamond) as shown in Figure 10, or grouped according to their functions as given in Table 2 (both reproduced from [20]).

Slightly different functional groupings and lists can also be found in [4, 6], reproduced in Table 2 and Table 3. These present different approaches to the collection and structuring of information for future technology studies. More details of specific methods can be found in [4, 6].

Note that the CBM Technology Impact study is not explicitly intended to invoke future scenario development methods or forecasting methods for future innovation in the military context.

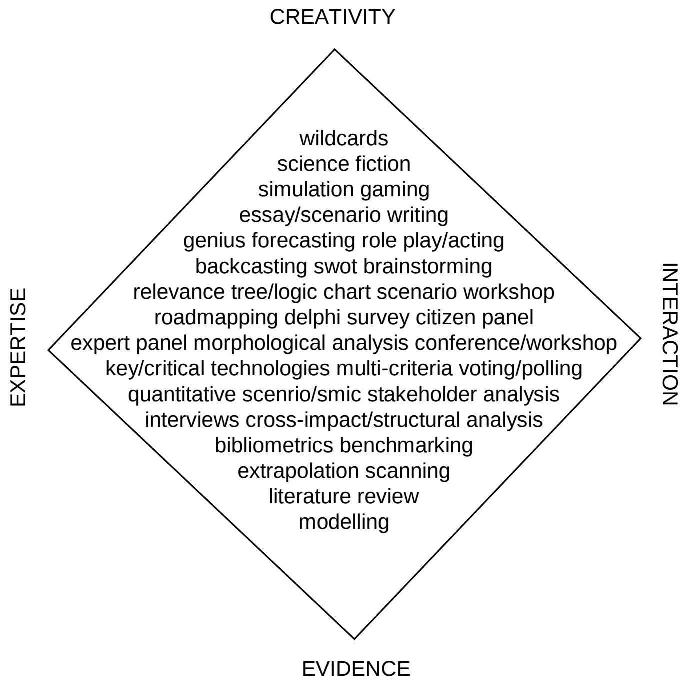

Figure 10: Technological forecasting methods grouped by characteristics [20].

Table 2: Functional groupings for technological forecasting methods [20].

Understanding	Synthesis & Models	Analysis & Selection	Transformation	Actions
Scanning	Gaming	SWOT analysis	Back-casting	Priority lists
Bibliometrics	Scenario planning	Multi-criteria analysis	Road-mapping	Critical/key technologies
Literature review	Wildcard analysis	Cross-impact analysis	Relevance trees	R&D planning
Interviews	Weak signals	Prioritisation/Delphi	Logic Charts	Action planning
Trends/Drivers Indicators	Modelling	Scoring/rating	Linear programming	Operational planning
Systems analysis	System simulation	Benefit/cost/risk analysis	Strategic planning	Impact assessment

Table 3: Forecasting methods for future innovation in the military context [4].

Extrapolation of current trends	Group consensus	Historical analysis	Generation of alternate futures
Environmental scanning: systematic review of literature/SME opinions	Delphi – individual experts are surveyed, results collated and returned to participants for further refinement	Analysis of technological drivers and their impact on military operations	Field Anomaly Relaxation (FAR) – creating scenario space that spans the range of activities that might evolve in the future
Emerging issues analysis: identifying pertinent trends	Determining key indicators necessary for realisation of particular technologies		Discrepancy analysis and comparison of futures using pair-wise comparison of FAR factors
	Steps for considering integration of technologies		

Table 4: Functional groupings for future scenario development [6].

Collecting judgements	Forecasting time series/ other quant. measures	Understanding linkages between events, trends, and actions	Determining a course of action in presence of uncertainty	Portraying alternate plausible futures	Understanding state of future	Tracking changes and assumptions	Determining system stability
Genius	Econo-metrics	System Dynamics	Decision Analysis	Scenarios	State of the Future Index	Environ-mental scanning	Non-linear techniques
Delphi	Trend Impact Analysis	Agent Modeling	Road Mapping	Futures Wheel		Text mining	
Futures Wheel	Regression Analysis	Trend Impact Analysis	Technology Sequence Analysis	Simulation Gaming			
Group meetings	Structural Analysis	Cross Impact Analysis	Genius	Agent Modelling			
Interviews		Decision Trees					
		Futures Wheel					
		Simulation Modelling					
		Multiple perspectives					
		Causal Layered Analysis					
		Field Anomaly Relaxation					

Appendix C. Military Environment Considerations

The following considerations have been identified as pertinent for military systems when considering the impact of technologies:

- security and sensitivity of information [4]
- cost [4]
- capacity to readily access components and whole systems [4]
- length of procurement cycle for capabilities [4]
- global nature of science and technology, which affects availability and sustainability of the Intellectual Property/knowledge/skill/manufacturing base in times of competing interests and local policies [4]
- desire of many nations to integrate military capabilities into joint, combined and network-enabled force structures [26]
- value of investment being typically measured in terms of its impact on campaign or policy-level measures of effectiveness [26]
- difficulty in identifying practical metrics because of indirectness of cause and effect chains and difficulty in measuring complex effects produced by military action [26].

Appendix D. Input and Output Impacts Spreadsheets

For brevity, in the following spreadsheets we refer to the eight FIC categories by number:

1. Command and Management
2. Organisation
3. Major Systems
4. Personnel
5. Supply
6. Support
7. Facilities
8. Collective Training

D.1. Input Impacts Spreadsheet

ID	Title	Description	Indicative $$$ COSTS	Indicative $$$ SAVINGS	Stakeholders	Assumptions	FIC
1	**Leadership at high level and local level**	**Personnel at decision-making level and at user-level who actively promote implementation of the capability**	**Labour costs, administrative costs**	**Reduced administrative costs associated with delays in implementation**	**ADF policy-makers, capability development/acquisition organisations, equipment operators, logistics personnel, maintenance personnel**		**1,2,4**
2	**Incorporation of CBM requirements into the capability acquisition process**		**Labour costs, including relevant skilled personnel, administrative costs, travel costs, documentation costs, research costs (TRAs, BOPs, market surveys, etc.)**	**Reduced administrative costs associated with delays in implementation, a greater chance of getting a CBM solution that 'works' and getting such a solution after fewer iterations**	**Materiel suppliers, capability development/acquisition organisations**		**1,2,3,5**
2a	Tracking of technology developments						
2b	Involvement of industry	This is to take advantage of the benefits of CBM throughout the existing logistics system and supply chain, to develop maintenance processes and paradigms that do not conflict with original OEM guidance, and to take advantage of that which has already been developed in industry (e.g. libraries of diagnostic and prognostic algorithms, characterisations of failure patterns, etc).					
2c	Allocation of ownership and management responsibility						
2d	Assessment of CBM solutions early in the design stage.						
2e	Allocation of funding for CBM capability	Including for ongoing support, with a commitment not to barter away this funding during project development/reviews etc.					
2f	Inclusion of CBM requirements into acquisition of relevant equipment/platforms	Business cases for CBM have been identified as a major weakness from an acquisition manager's point of view and often mean that promising technologies are not adopted during design and development.					
2g	Development of CBM requirements	This includes development of key performance parameters, specific monitoring and sensing limits, appropriate system actions etc. Part of this involves identifying who needs the data, when, and where (timeliness requirements etc. - I have a list of these things somewhere). There is a suggestion that analysis should be kept to the lowest level possible, e.g. Unit level to facilitate timely decision support for maintainers.					
2h	Development of business case for CBM						

ID	Title	Description	Indicative $$$ COSTS	Indicative $$$ SAVINGS	Stakeholders	Assumptions	FIC
3	**Change management**	**System integration at the organisational level - a rethinking of relationships between individual organisational 'pieces' to enable the advantages of CBM to be realised.**	**Labour costs, administrative costs, travel costs, costs of developing and distributing documentation (e.g. SOPs); IT/tech support cost increases during roll-out; loss of productivity during roll-out; central management costs; costs of pilot trials; cost of research and optimisation studies**	**Reduced administrative costs associated with delays in implementation; reduced productivity losses during implementation; reduced losses due to resistance to implementation**	**capability development/acquisition organisations, equipment operators, logistics personnel, maintenance personnel, fleet managers**		**All**
3a	Development of new logistics and maintenance structures and processes	This includes developing a CBM-driven spare parts inventory strategy; developing the appropriate maintenance policy/actions to take in response to specific diagnostic/prognostic signals; updated Electrical and Mechanical Engineer Instructions (EMEIs), Standard Operating Procedures (SOPs), Repair Parts Stores, service manuals, and operator manuals; and a redesign of where maintenance activities fall within the Lines of Support, at what nodes within the maintenance network, and by what assets.				Without simultaneous optimisation of logistic and maintenance processes in conjunction with the implementation of CBM, a lot of the potential benefits of CBM will be eroded. The new logistics and maintenance structures and processes must not be overly complex or burdensome, and must not rely on maintenance staff to expend large amounts of extra time.	
3b	Allocation of resources for implementation and facility upgrades						
3c	Promotion of benefits	This includes promotion of benefits to both end users (maintainers and operators) and to fleet managers and commanders.				Once commanders are supportive, the ability to have CBM supported across all levels is greatly enhanced.	
3d	Monitoring of implementation	This includes not only monitoring the progress of the initial implementation of CBM, but also ongoing monitoring, e.g. assessing the CBM system outputs against post failure investigations (failure of the CBM system).					
3e	Amendment of existing maintenance contracts with civilian agencies	This is especially important where e.g. scheduled maintenance is a condition of sale.					
3f	Human resource management	Analysis of the changes to human resource requirements and the appropriate actions required to satisfy these requirements.					
3g	Rollout scheduling and implementation						
3h	Doctrinal synchronisation	This includes updating policy documents; doctrine; documentation for SOPs and Tactics, Techqnues and Procedures (TTPs), etc.					
3i	Design of ongoing support	The design of CBM support mechanisms for in-service fleets requires consideration.					
3j	Establishment of supply chain and contracts for physical CBM technology parts and module repairs						

ID	Title	Description	Indicative $$$ COSTS	Indicative $$$ SAVINGS	Stakeholders	Assumptions	FIC
4	**Acquisition of HUMS-enabled equipment/platforms or modification of existing platforms**	**Cost of HUMS-enabled platform purchase is comparable to purchase of platforms without HUMS, as it is becoming standard technology**	**Cost of platform purchase; for modification of legacy platforms this includes the cost of tracking existing and evolving technologies, research, engineering, assembly and installation; cost of acquisition of physical HUMS/CBM hardware and software (e.g. sensors, data loggers), an initial supply of spare parts, and associated warehouse management; cost of testing, certification and trials; cost of offboard components, such as the data warehousing solution; platform maintenance costs (labour, spare parts); cost of revised platform maintenance (links to Doctrinal Synchronisation). Cost of labour, technical support, specialised tools and equipment, administrative costs in contract management, and software support, updates and licencing.**	**Increased disposal value of assets**	**Materiel suppliers, capability development/acquisition organisations**		**2-7**
4a	Acquisition of HUMS/CBM hardware and software	Includes the relevant sensors, Built-In Test Equipment (BITE), displays, data acquisition and processing software and hardware including off-board systems. At the least, this should be considered now for future purchases, but existing procedures such as oil sampling can be utilised more widely in the interim.				HUMS/CBM equipment requires minimal corrective costs.	
4b	Design of HUMS/CBM hardware and software maintenance	This involves the set-up of supply/maintenance contracts; testing, repair and replacement of components; software upgrades, patches and licensing, sensor calibration. This must also take into account adjustments of the CBM solution as the target platform evolves and ages, and as CBM solutions evolve and mature (particularly software, but also hardware).					
4c	Increased complexity of equipment/platforms	This is not only as a product of the adoption of CBM, as platforms and technology will continue to increase in complexity regardless.					
4d	Revised Equipment/platform maintenance	It may be possible to draw guidance and advice from civilian agencies or other military agencies that use CBM technology.				The cost of maintaining HUMS-enabled platforms is likely to be similar to the cost of maintaining platforms without HUMS. Given that current processes are likely to be in need of review anyway, performing a review that considers CBM is not likely to cost much more than performing a review that does not consider CBM.	
4e	Increased modularity of equipment/platform design	As with equipment/platform complexity, this is not exclusively a product of the adoption of CBM technologies, as there is an existing trend for modularisation and repair-by-replacement.					

ID	Title	Description	Indicative $$$ COSTS	Indicative $$$ SAVINGS	Stakeholders	Assumptions	FIC
5	**Data management strategy**	**Having an easy to use, quick response and easy data management system is universally acknowledged within the maintenance area as a vital 'efficiency multiplier'.**	**Research and documentation costs for algorithm development; cost of research and optimisation studies; cost of pilot trials; labour and administrative costs for implementation; cost of using and maintaining ICT infrastructure, personnel recruitment and/or retraining.**		**capability development/acquisition organisations, logistics personnel, maintenance personnel, security organisations, data analysts, operational planners, ICT managers, IT/signals personnel**		**1-4, 6**
5a	Data architecture and standards						
5b	Data protection, security and transmission protocols	This includes data encryption.	May create substantial overhead in information processing and handling.				
5c	Data collection and storage processes						
5d	Bridging the 'air-gap' between equipment/platforms and data processing systems						
5e	Data ownership strategies	Includes consideration of data-sharing with Defence contractors/OEMs(28,33), privacy issues (40)					
5f	IT support	This may include the need for an increase in IT Support personnel or retraining of existing personnel.					
5g	Data mining, analysis and use for decision-support	This may include employing personnel for the specific purpose of CBM knowledge management					
5h	Development of algorithms (prognostics and diagnostics)						
6	**Training and personnel recruitment/certification**	**This includes in the use of sophisticated analysis, decision support and scheduling tools, training of maintenance staff and fleet managers, acquisition of personnel capable of assessing CBM solutions, less emphasis on detailed sub-system knowledge and more on being able to effectively manage to meet operational goals. Training for operators will be critical so that monitoring is conducted (e.g. oil-sampling). Some additional training will be required for maintenance personnel, but no significant additional training reuired for the maintenance processes themselves (e.g. performing the same Preventive Maintenance activities but at different times/through different triggers).**	**Cost of developing training protocols/SOPs; cost of publishing and distributing training manuals and user/repair manuals; cost of implementing training (time, instructors, equipment, facilities, associated support); loss of productivity during training; cost of complying with qualification/certification requirements. Potential for resource-neutral delivery, if integrated with the routine modernisation of training within Corps Schools, but not resource-neutral in terms of development of the new material, courses, etc.**	**Reduced costs of inappropriate equipment use; maximising overall CBM-related savings through extensive and appropriate utilisation of the technology.**	**capability development/acquisition organisations, end-users, logistics personnel, maintenance personnel, data analysts, training personnel**	**There is the potential for resource-neutral delivery of training, if the changes can be integrated with the routine modernisation of training within Corps Schools.**	**1,2,4,6-8**
6a	Modification of maintenance training facilities	Training in the use of CBM and related technologies may require changes to the equpment and facilities used to deliver the training.					

ID	Title	Description	Indicative $$$ COSTS	Indicative $$$ SAVINGS	Stakeholders	Assumptions	FIC
7	**Technology integration**	**Much of this is linked with the acquisition of HUMS-enabled platforms or modification of legacy platforms.**	**cost of advanced engineering; cost of assembly and installation; cost of testing/trials; cost of external system modifications (to the Logistics Information System, Enterprise Resource Planning (ERP) systems, Command and Control systems, etc.); cost of developing and distributing technical data (e.g. operating manuals, troubleshooting manuals); cost of using and maintaining existing ICT infrastructure; technical support costs; cost of signal/bandwidth management.**	**Reduced purchase cost of non-HUMS enabled equipment.**	**Materiel suppliers, capability development/acquisition organisations, ICT managers**		**1-7**
7a	Development of and integration with Defence ICT infrastructure	This may involve modifications to the Logistics Information System, Battlefield Management System, Communication systems, Defence Local Area Networks, SATCOMS, signal/bandwidth management etc. to facilitate the introduction of CBM.					
7b	Mutual integration of HUMS/CBM hardware and software, and with platforms.	This will involve integration with other systems, e.g. Logistics Information System, Battlefield Management System, Communication systems, etc (i.e. existing fielded systems). One approach may be a long term programme of progressive introduction, to allow CBM-enabled systems to interoperate and work in parallel with traditional systems.				A key to end-user acceptability will be implementation/integration that does not require the use of a 'separate computer', especially not a separate computer for each system/subsystem operating under a CBM regime.	

D.2. Output Impacts Spreadsheet

ID	Title	Description	Indicative $$$ COSTS	Indicative $$$ SAVINGS	Stakeholders	Assumptions	FIC	+ / -/?	(S)hort, (M)edium or (L)ong-term	(D)irect/ (I)ndirect
1	**Immediate functions**									
1a	Diagnostics	Real-time assessment of equipment/platform health, including the use of Built-in Tests/Built-in Test Equipment (BIT/BITE)	As per costs of inputs to capability; increased cost of minor parts replacement on 'as-required' basis	As per savings from impacts	Equipment operators, maintenance personnel		3,4,6	+	S	D
1b	Prognostics	Identifying existence of a fault and impending failure	As per costs of inputs to capability; increased cost of minor parts replacement on 'as-required' basis	Reduced cost of scheduled parts replacement; reduced unplanned maintenance costs	Equipment operators, maintenance personnel	That the quality of collected data is sufficient for prognostic purposes and accurate prognostic models are available.	3,4,6	+	S	D
1c	Automated generation of (near) real-time equipment/platform health information	Timeliness of equipment health information is critical in decision-making processes, particularly for Unit-level maintenance.	As per costs of inputs to capability	Reduced costs of reporting and data collation	Equipment operators, maintenance personnel, logistics personnel, operational planners	That the 'air-gap' between the equipment/platform and data analysis systems can be satisfatorially bridged to provide automatic data transmission	1-4,6	+	S	D
2	**Effects on Equipment/ Platform and of Integration with other technologies**									
2a	GPS: Improved visibility of fleet position		cost of maintaining networks and infrastructure, including IT support; technology integration costs	efficiency gains in asset utilisation	Operational planners, logistics personnel	That GPS tracking technology can be integrated satisfactorially with CBM and C2 systems (e.g. to satisfy data security concerns related to GPS tracking while on deployment)	1,3	+	S/M	D
2b	Tracking of position, status and load of vehicles, critical stores and drivers		data acquisition, collation, processing and analysis costs	efficiency gains in asset utilisation, reduced maintenance burden through correct usage of equipment (e.g. not overloading or exceeding the design envelope), increased visibility of assets/stores throughout the supply chain	logistics personnel, fleet managers, operational planners, supply personnel		1,3,4,6	+	M	D
2c	Increased complexity/modularity of technology	As in the corresponding Input Impacts, this is not an exclusive result of the introduction of CBM. Could be both positive and negative.					3,6	+/-	S/M/L	I

ID	Title	Description	Indicative $$$ COSTS	Indicative $$$ SAVINGS	Stakeholders	Assumptions	FIC	+ / - /?	(S)hort, (M)edium or (L)ong-term	(D)irect/ (I)ndirect
3	**Effects on workforce/workforce skill base**									
3a	**Reduced vs. Increased maintenance training requirements**	Reduced maintenance training requirements may only be at the 'junior' level, with more senior maintainers requiring an unchanged amount of training. Conversely, there may be a potential increase in training requirements for senior maintainers in the area of data analysis.		Reduced cost of training and maintaining qualification	Equipment operators, maintenance personnel		2,4,6-8	+	M/L	I
3b	**Reduction vs. no reduction in traditional diagnostic and maintenance skills.**	A reduction in the traditional maintenance skills can be associated with increase in complexity of technology in general, not necessarily as a direct result of CBM itself, but of digitisation of equipment and reduction in the cost of ICT technologies - it becomes cheaper to replace a whole unit than to put expensive labour into repairing cheap parts (S2, S3). Conversely, there may be no loss of the traditional skills as the requirement to conduct Preventive Maintenance will still exist within a multitude of equipment/platform variants not fitted with CBM technology. There may also be an improvement in best work practices in line with modern industry standards commonly practiced by larger organisations.	Cost of outsourcing repairs; cost of replacement modules	Reduced costs of training and maintaining a range of qualifications	Equipment operators, maintenance personnel	Whether or not there will be a significant decrease in the requirement for traditional diagnostic and maintenance skills	2,4,6,8	?	M/L	I
3c	Increased IT literacy of maintenance personnel				maintenance personnel		4,8	+	M/L	I
3d	Ongoing training, including personalised training, for users/operators	Personalised training for operators refers to driver-feedback mechanisms that allow tailored training to be delivered. Ongoing training for upskilling of maintenance personnel may be required for them to gain an understanding the holistic system.		As above			4,6-8			
3e	Increased demand for IT support personnel	Relates to the increase in IT Support requirements	recruitment costs, training costs, potentially more wages to be paid		IT/signals personnel		4,6	?	M	I
3f	Increase in personnel capable of implementing and upgrading CBM systems		recruitment costs, training costs, potentially more wages to be paid		maintenance personnel		4,6	?	S/M	D
3g	**Potential reduction vs. unlikely reduction in the number of maintainers.**	If CBM diagnostics and prognostics work well then maintenance can be scheduled such as to reduce the number of maintainers required to sustain a fleet although this will be in the longer term and reductions may be minor. Conversely, there may be a personnel-neutral solution but with changes in competencies, e.g. a decrease in traditional maintenance activities but an increase in data analysis.			maintenance personnel		4,6	?	M	D

ID	Title	Description	Indicative $$$ COSTS	Indicative $$$ SAVINGS	Stakeholders	Assumptions	FIC	+ / - /?	(S)hort, (M)edium or (L)ong-term	(D)irect/ (I)ndirect
3h	Decrease the skill/technology gap between Defence and civilian agencies	CBM technologies will become increasingly similar between Military and commerical/civilian agencies, as (hopefully) each will drive the other.					4,6,7	+	M/L	I
3i	Reduced scope for innovative operator repair for platform 'revival' to complete a mission						3,4	-	M/L	I
3j	Increased non-technical maintenance role for operators cf. increased modularity						3,4,6	+	M/L	I
4	**Immediate maintenance effects**									
4a	Reduced preventive maintenance requirements	Associated with a reduced No Fault Found (NFF) rate, and the potential to extend service intervals of some subsystems.		Reduced cost of preventive maintenance, including labour, parts, plant activity	Equipment operators, maintenance personnel, logistics personnel		1,3-6	+	S/M	D
4b	**Less regular or more proactive (rather than reactive) maintenance vs. no decrease in regular maintenance.**	Less regular, more proactive maintenance is associated with a move from usage-based or time-based scheduled maintenance to condition-triggered maintenance (i.e. CBM). Conversely, the service interval may still remain relatively constant to allow for vehicle availability, in particular for scheduling to fit in with unit commitments - something that is particularly relevant for for field units. If servicing is conducted purely on condition based triggers, it may be difficult to schedule servicing to meet the Commanders' commitment during the training year. Other views are that HUMS/CBM will allow for 'better' planning. The contextual differences between in-barracks vs. on deployment operation may be worth teasing out here.		Reduced cost of preventive maintenance, including labour, parts, plant activity; reduced cost of unnecessary maintenance	maintenance personnel, logistics personnel		1,3-6	?	S/M/L	D
4c	Improved fault detection	Quicker and more accurate fault detection through diagnostics and prognostics		Reduced cost of labour for fault-detection/inspections	Equipment operators, maintenance personnel		3,4,6	+	S	D
4d	Improved visibility of expected parts demand			Reduced reliance on urgent means of transportation for spare parts	Maintenance personnel, supply personnel		4-6	+	S/M/L	D

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4e	Reduced requirement for manual data entry	Also reduces the potential for human-induced errors to be introduced into the data.		Reduced labour and administrative costs associated with manual data entry	Equipment operators, maintenance personnel	That the 'air-gap' between the equipment/platform and data analysis systems can be satisfatorially bridged to provide automatic data transmission; successful integration of relevant software systems	4,6	+	S	D
4f	Reduced errors/misdiagnosis rate			Reduced cost of unnecessary maintenance and secondary (maintenance-induced) damage	Equipment operators, maintenance personnel		3,4,6	+	S/M	D
5	**Resource consumption effects**									
5a	Reduced resource (e.g. Petrol, Oil and Lubricant (POL)) usage rate	This could be achieved via adjustment of vehicle configuration parameters. It will also include a reduction in disposal costs due to less consumption. A reduction in POL usage rate is particularly relevant for vehicles with high lubricant/coolant volumes and low usage rates. In such instances the fluids tend to be changed based on calendar time. This is more a function of HUMS more than of CBM itself.		Reduced cost of resources e.g. POL	Logistics personnel, equipment operators, supply personnel		1,5	+	M/L	I
5b	Reduction in consumption of some spare parts, increased consumption of others	Decreased consumption of 'consumables' such as coolant, engine oil. Potential increased consumption of replacement parts due to earlier Preventive Maintenance intervention.	potential increase in consumption of some types of spare parts	potential reduction in consumption of some types of spare parts	maintenance personnel, logistics personnel, supply personnel		5	+	S/M	D
6	**Data collection and analysis effects**									
6a	Increased requirement for data management/data analysis/data mining skills, and for specific data and information analysts	This includes increased complexity of data-related tools, and specialisation of personnel. The data analyst role could be filled by senior maintenance staff. The data analysis and mining includes reporting to both the end users (maintainers and operators) and to higher level fleet managers.	HR costs in recruiting and training relevant personnel; contracting and software licensing costs in outsourcing this function		data analysts, IT/signals personnel, materiel suppliers		2,4,6	?	S/M/L	D
6b	Increase in data storage and processing requirements	This includes both off-platform storage and processing and the requirement for on-platform processing, where computing power may be limited compared to e.g. a dektop or laptop PC.	labour and administration costs, IT support costs, software acquisition and processing costs, cost of collecting and analysing data		data analysts, capability development/acquisition organisations, IT/signals personnel		2,4,6	-	S/M/L	D

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6c	Increase in the quality and quantity of available equipment/platform health and usage data	This includes system Remaining Useful Life (RUL) and fleet Life Of Type (LOT) information, i.e. 'total fleet intelligence'. It is worth noting that an increase in quantity of data is not a benefit if the data is not useful. This data may include information on both running costs and maintenance costs.	cost of data transmission, storage and processing; associated administration and labour costs; cost of ICT infrastructure and maintenance of that infrastructure		Data analysts, IT/signals personnel, fleet managers, operational planners, logistics personnel, capability development/acquisition organisations, research and academic organisations	That data download and recording is not neglected by maintainers (e.g. due to inadequate implementation, over-sensitivity, and/or no demonstration of observable benefits)	1-7	+	M/L	D
6d	Improved diagnostic and prognostic capability	This is associated with the development of new algorithms for diagnostics, prognostics and decision-support, including learn-as-you-go approaches.	Cost of research, trials, documentation, including associated labour, administration and travel costs; data collation and analysis costs; cost of maintaining relevant ICT infrastructure; cost of licensing relevant business analytics software	Flow-through of cost savings associated with more efficient maintenance and increased equipment life	Materiel suppliers, data analysts, research and academic organisations	Funding and contractual arrangements are in place for long-term research	2,3,6	+	L	I
6e	Improved data availability for incident/accident investigation	Improved availability will facilitate physics-of-failure analysis, post-failure analysis as well as accident investigation	Costs in setting up the legal framework for use of the data for this purpose	Potential reduction in costs associated with accidents including claim payouts	Equipment operators, maintenance personnel, accident/incident investigators, legal personnel, training personnel	That processes are in place to deal with legal/HR management implications of the collected data (e.g. for cases of equipment misuse)	2,4	+	M/L	I
6f	Improved data analysis/data mining techniques	It may be that such techniques are developed as a result of the introduction of CBM, but it may be that existing techniques from the commercial sector/academia are adequate.	Cost of data collation and analysis; cost of research and documentation; cost of relevant ICT infrastructure; cost of software licensing	Efficiency gains in equipment maintenance and usage with more accurate algorithms	capability development/acquisition organisations, data analysts, research and academic organisations	Funding and contractual arrangements are in place for long-term research	2,3,6	+	L	I
6g	Improved data availability for engineering change proposals	This includes proposals for changes as part of mid-life upgrades and during 'deep' maintenance/condition-based reset	Data analysis costs, including labour and administrative costs	Efficiency gains in development of engineering change proposals	capability development/acquisition organisations		3	+	L	I
6h	Improved monitoring of environmental pollution effects	Including e.g. the monitoring of exhaust emissions and other gases	Potentially costs of additional sensors and their integration; cost of collating and analysing information	Potentially reduced cost of compliance with environmental legislation	ADF as a public entity, legislative bodies (external to Defence), data analysts, Australian public	That emission monitoring may become more prominent in future legislation	2	+	M/L	D
6i	Greater availability of terrain and environmental data		Cost of data collation and analysis; cost of research and documentation (8); cost of relevant ICT infrastructure; cost of software licensing	Efficiency gains in equipment maintenance and usage with more accurate algorithms	capability development/acquisition organisations, research and academic organisations, data analysts, equipment operators, maintenance personnel	The HUMS system onboard mobile platforms, such as vehicles, records terrain and environmental data	3,4,6,8	+	L	I

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6j	Improved ability to estimate equipment/platform condition				Maintenance personnel, operational planners		1,3,6	+	M	D
6k	Higher reliance on data collection/storage/management/exploitation	This is likely to be a result of the use of HUMS data in decision-making at many levels in the organisation.	Cost of data collation and analysis; cost of research and documentation; cost of relevant ICT infrastructure; cost of software licensing		maintenance personnel, logistics personnel, operational planners, fleet managers		4-6	-	M/L	I
6m	Improved monitoring of health/usage and health/usage trends	This is especially useful for military equipment with varying patterns of use			Fleet managers, maintenance personnel, data analysts		1-6	+	M	D
6n	Improved knowledge base for decision support for future capability acquisitions	This facilitates improvements in construction of Functional Performance Specficiation/Request for Tender (FPS/RFT) documents, and improved decision support at global, sub-fleet and local levels.	Research and documentation costs; administrative, labour and travel costs; data collation and analysis costs		capability development/acquisition organisations, data analysts	A concerted effort is made to analyse information and incorporate findings into capability acquisition process	1-3	+	L	I
6o	Improved ability to estimate overall condition of the fleet	This includes assessments/estimations in real-time or near real-time when deployed.			Fleet managers, operational planners, strategic planners, capability development/acquisition organisations		1-3,5,6	+	M/L	D
6p	Improved operator training	This may be achieved through enhanced or personalised training afforded by HUMS feedback	cost of data collation and analysis; cost of amending training protocols	Potential reduction in costs associated with accidents, recovery, repairs and injury management	Equipment operators, training personnel, ADF policy-makers, data analysts	That a concerted effort is made to analyse and use collected accident/usage data to amend training protocols, and that personnel are employed to tailor training to individual operators	1,2,4,8	+	L	I
7	**Data-transmission effects**									
7a	Significant increase in data transmission requirements	This includes increases in both the volume and timeliness/speed requirements of data transmission.	Cost of ICT infrastructure and network/bandwidth management; cost of IT support		capability development/acquisition organisations, IT/signals personnel		1-3,6,7	-	S/M/L	D
7b	Increase in requirement for bandwidth/networks for transmission of bulk data, including contention for bandwidth	Transfer of HUMS data in a deployed situation is likely to be in competition with many other data transmission requirements, and is likely to be of a lower priority than other traffic such as situational awareness data, especially if being transmitted over the same bearer.	Cost of ICT infrastructure and network/bandwidth management; cost of IT support		capability development/acquisition organisations, IT/signals personnel		1-3,6,7	-	S/M/L	D

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7c	Increased ability of unauthorised external parties to access generated data	With increased data transmission comes an increase in the potential for unautorised external parties to gain access to that data.			Materiel suppliers, external commercial organisations, enemy forces, operational planners, IT/Signals personnel		1-3,7	-	S/M/L	I
7d	Increase in IT support requirements		IT support costs, including additional personnel		Operational planners, IT/signals personnel		1,6	-	S/M/L	D
7e	Increased potential for compromise of operationally-significant information	This is true of data transmissions that can alert external parties to the location of vehicles if GPS tracking is integrated into the HUMS; transmission of location and status of an entire fleet is problematic from an operational security perspective.	potential costs of data security breaches and leaking of operationally important information		External commercial organisations, enemy forces, operational planners, IT/signals personnel		1-3,6,7	-	S/M/L	I
7f	Increase in data security management requirements	For example, this is necessary to address the security issues surrounding the transmission of bulk of data from the area of operations.	increased data protection costs		Operational planners, IT/signals personnel		1,6	-	S/M/L	I
8	**Changes in logistic processes**									
8a	Shift from repair-focus to module replacement	Associated with increasing complexity of technology in general	Increased cost of replacement modules	Reduced cost of repairs and training of maintenance personnel	maintenance personnel, supply personnel		3-6	?	M/L	I
8b	More efficient and responsive supply processes	This may be achieved through a reduction in Administrative and Logistics Down Time (ALDT) delays; improved spares availability, a reduction in stock-outs, correct type and stocking levels of replacement parts and lubricants; better predictive stocking of high usage spare parts based on the work effort being applied to the equipment in a particular unit and not based on recent usage rates as a sole means of determining the stock holding. The latter is particularly advantageous when a Unit increases its work tempo without the recent usage rate data to trigger changes to stock holdings.	reduced labour costs in generation of demands	Reduced reliance on urgent means of transportation for spare parts; reduced inventory holding costs; maximisation of contracting opportunities	Logistics personnel, supply personnel, maintenance personnel	That combined optimisation of maintenance and supply processes takes place	1,2,4-7	+	L	I
8c	Reduced inventory holdings at supply chain nodes	It is conceivable that this could be achieved through a reduction in holdings of consumable items like lubricants etc. and potentially a reduction in Repair Parts Stores stock holdings, but is most likely to be achieved in an in-barracks setting rather than when on deployment.	Potentially increased cost of replacement (vs repair) parts	Reduced inventory holding costs, transportation costs (especially for urgent demands), overall operating costs	Supply personnel, logistics personnel, operational planners	That there is sufficiently responsive supply of parts from the National Support Base (NSB)/Original Equipment Manufacturer (OEM) nodes. Requires the development of spare parts inventory control strategy potentially driven by CBM.	1,5,7	+	M/L	I
8d	Increased Information and Communication Technology (ICT) in workshops	This is primarily associated with automated collection and transmission of vehicle health and usage information, and the increased use of this information for decision support. Increased ICT in workshops is a trend that is already happening.	costs involved with procuring and maintaining the appropriate ICT, including hardware and software; training costs.		maintenance personnel, logistics personnel		6,7	?	S/M	D

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8e	Increased ability for logistics/CSS personnel to analyse data (e.g. POL usage) to inform the management of equipment (vehicle) resources.			better informed decisions regarding logistics management, potential for more streamlined supply chain, potential for reduced inventory holdings at supply chain nodes, etc.			1,5	+	S	I
8f	Requirement for integrated changes in maintenance and supply processes		Change management costs, including training, Standard Operating Procedure development, administration costs, monitoring costs	Productivity/efficiency gains due to maintenance and supply optimisation	ADF policy-makers, logistics personnel, maintenance personnel, supply personnel		1,2,4-7	?	S/M	D
8g	Change to proactive, CBM-driven supply processes, including for spare parts, POL, etc.	May be associated with Autonomic Logistics processes such as automatic re-ordering/resupply, sense-and-respond actions.	Change management costs, including training, Standard Operating Procedure development, administration costs, monitoring costs	Reduced labour costs in generation of demands	Maintenance personnel, supply personnel, logistics personnel	That combined optimisation of maintenance and supply processes takes place. Any efficiency gains depend on the Enterprise Resource Planning tools used and design of the supply system in general - supply of spares is but one facet within a broader logistic supply system for many other commodities.	1,2,4-6	+	M	I
8h	Reduced logistic footprint	Noting that for a given level of logistics capability, any spare space is likely to be taken up by other supplies/functions.		Reduced inventory holding costs; reduced transportation costs (especially for urgent modes); reduced cost of spares; reduced logistic footprint ownership costs	Logistics personnel, maintenance personnel, operational planners, supply personnel		1,5-7	+	M/L	I
8i	Negligible impact on supply chain costs	Potentially in conflict with other assertions surrounding reduced footprint and usage, better planning, better management etc..					5-7			
8j	Improved management of maintenance/sustainment contracts, and of warranties for components/platforms	For example, HUMS data can provide an objective assessment of the fulfilment of contractural obligations, or through assessing the quality of the platform for contractural/payment purposes.		reduction in legal fees, admin related to warranty claims, admin related to evaluating if contractual obligations have been met, improved contractual outcomes, improved warranty outcomes			1,6	+	M/L	I
8k	Improved remote assistance capability	The notion of tele-maintenance, or at least remote maintenance assistance, becomes feasible with the collection of (near) real-time health and usage data, where advice can be provided by a small set of Subject Matter Experts (SMEs) without requiring those SMEs to travel to the location of the maintenance support requirement.	Data-transmission costs	Reduced cost of vehicle and/or SME transportation to the site of equipment failure	Equipment operators, maintenance personnel, equipment/maintenance Subject matter experts	That equipment/platform status information can be transmitted over long distances in (near) real-time	4,6	+	S/M	D

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8m	Increased availability of space/infrastructure for other logistic functions			Reduced transportation costs for logistics infrastructure	Logistics personnel, operational planners	That labour and space savings are significant enough to make a difference overall, and are not diluted by the maintenance requirements of the CBM system itself	1,5-7	+	M/L	I
8n	Better supply planning, and improved planning, forecasting and budgeting of maintenance for deployment.			ability to position inventory in a more informed manner			1,5	+	M	D
8o	Management of CBM components within the supply chain	This refers to the physical components that make up a CBM system, e.g. sensors and data loggers, that were not previously part of the supply chain.	increase in footprint due to new spare parts being inserted	potential reduction in overall total inventory			5	?	S	D
9	**Longer-term maintenance effects**									
9a	Improved ability to plan maintenance, e.g. ability to schedule maintenance activities in a load-balancing way across the available service utilities	Associated with the ability to predict impending parts failure, conduct "Predictive" maintenance, track components/major subsystems, analyse maintenance procedures , adjust inspection intervals.		Reduced reliance on urgent modes of transport for repair parts; reduced losses due to equipment downtime; efficiency gains in maintenance scheduling	Fleet managers, maintenance personnel, operational planners, logistics personnel	That CBM-generated information is utilised appropriately to plan and optimise maintenance. This requires a maintenance and fleet management system that allows for "flexible (health-based) maintenance scheduling" rather than pre-planned scheduled maintenance.	1-6	+	S/M/L	I
9b	Improved ability to distribute equipment/platform workload	To be achieved through the ability to rotate highly utilised vehicles/equipment to units with lower usage rates to "even out" the usage of the fleet.		Reduced fleet replacement costs via improved through-life management	Fleet managers, maintenance personnel	That CBM-generated information is utilised appropriately to distribute equipment/platform workload. Appropriate changes must also be made to other parts of the organisation that are affected.	3,6	+	M/L	I
9c	Better targeted maintenance and upgrades throughout equipment/platform life	For example, this may be achieved through refinements to Preventive Maintenance regimes, better targeted 'deep' maintenance or 'condtion-based reset', and better informed mid-life upgrades.		Reduced maintenance costs over equipment life; reduced mid-life upgrade/deep maintenance costs	Fleet managers, maintenance personnel, logistics personnel	That appropriate changes are made to maintenance protocols.	1-3,6	+	M/L	I
9d	Improved operation/management/maintenance/sustainment of the fleet	This could be particularly true for old fleets that are approaching or have exceeded their Life of Type, and through identification of maintenance capability gaps.	change management costs in implementing new processes and training; associated labour and administrative costs; cost of data collation and analysis	Reduced cost of fleet repair, maintenance and replacement; improved fuel economy through more efficiently operating equipment	Fleet managers, maintenance personnel	That a concerted effort is made to capitalise on the CBM-generated information for improvement of fleet management processes	3,6	+	L	I

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9e	Reduced overall maintenance burden	This includes a reduction in "maintenance-induced" (maintainer-generated) maintenance in addition to potential reductions in Preventive and Corrective maintenance.		Reduced overall maintenance costs including labour, transportation, spare parts, test equipment	Maintenance personnel, logistics personnel	That CBM results in an overall decrease in maintenance requirements rather than just a change in the type of maintenance.	1,3-6	+	M/L	I
9f	Automated self-repair or self-adjustment of equipment	For example, automatic maintenance/adjustment of equipment (e.g. engine valves, calibration of targeting systems) based on data generated from diagnostics.	appropriate hardware and software development, procurement, maintenance etc., appropriate operator/maintainer training	Reduction in maintenance burden, e.g. reduction in repair time particularly for parts of the drive-train that are hard to access by human maintainers, reduction in the need to bring equipment into a workshop for (relatively) minor adjustments	maintenance personnel, equipment operators	That this attains cultural acceptance, i.e. being comfortable with automated adjustments	6	+	M/L	D
9g	Reduced corrective maintenance requirements	Achieved through forewarning of equipment degradation and pending equipment failure		Reduced corrective maintenance costs: repair, replacement, spare parts, labour; reduced reliance on urgent transportation of critical parts	Equipment operators, maintenance personnel		3-6	+	M	D
9h	Reduction in the amount of support equipment required in the field, reduced need for specialised support equipment at the strategic level	May come about through increased BIT/BITE and/or a commonality across embedded diagnostics/prognostics.		reduced equipment purchase costs; reduced transport costs	maintenance personnel, equipment operators		6,7	+	S/M	D
9i	Redesign of maintenance workshops with technical repair/refurbishment pushed rearward	This refers to having smaller 1st Line and larger 3rd and 4th Line facilities, and includes a reduced technical presence at Unit level. It follows from the trend toward modularisation and repair-by-replacement.	establishing the new structure and protocols/procedures	more efficient workshops	maintenance personnel		6,7	+	M/L	I
9j	Improved utilisation of tradespeople, particularly for Preventive Maintenance	This follows from better informed, better targeted maintenance.		increased ability to perform maintenance through increased productivity	maintenance personnel, workshop managers		4,6	+	S/M/L	D

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10	**Equipment/platform availability effects**									
10a	Improved safety in the operation of equipment/platforms			Reduced injury management costs	Equipment operators, passengers		3,4	+	M/L	I
10b	Reduced recovery requirements	Fewer operational failures while on deployment will reduce the requirement for equipment recovery, which is especially beneficial if recovery must occur under fire.		Reduced recovery costs and potential injury management costs; reduced indirect costs associated with recovery, e.g. delays	Equipment operators, recovery personnel, maintenance personnel, logistics personnel, operational planners		1,3,4,6	+	S/M	I
10c	Reduced operational failure rates and improved operational reliability of equipment/platforms	Having better insight/knowledge into the condition of individual vehicles/platforms, and of the fleet as a whole, will facilitate better informed decision-making when planning for deployment		Reduced costs of recovery, repair, replacement, personnel injury management, and indirect costs associated with operational set-backs	Equipment operators, passengers, recovery personnel, maintenance personnel, operational planners, logistics personnel		1,3,4,6	+	S/M	D
10d	Reduced catastrophic failure rates of equipment/platforms	This is associated with the reduced impact of equipment failure and reduced collateral damage through better information about equipment health.		Reduced repair and replacement costs; reduced indirect costs of catastrophic failure (delays, etc.); reduced rebuild requirements during depot overhaul; potential reductions in insurance costs	Equipment operators, maintenance personnel, fleet managers	Only if available HUMS data is acted on in a timely manner.	3,4,6	+	M	D
10e	Reduced equipment/platform down time	Could be achieved through improved diagnostics and a more efficient/effective supply chain		Reduced productivity losses due to maintenance	Equipment operators, maintenance personnel, operational planners, logistics personnel	That an effective spares pipeline and effective supply chain management is in place.	1,3,4,6	+	S/M	I
10f	Increase in operational availability and capability of equipment/platforms	Or, at the least, an increase in the confidence of equipment availability, facilitating more confident deployment planning.		Reduced cost of initial spares inventory; reduced costs associated with operational failures (including recovery, repair, injury management, and operational delays)	Equipment operators, maintenance personnel, operational planners, logistics personnel		1-4,6	+	S/M	D/I
10g	Increased/more predictable Equipment Life			Reduced cost of replacing equipment/platforms; increased return on investment (ROI)	Fleet managers, end-users, maintenance personnel, capability development/acquisition organisations		2,3,5,6	+	L	I

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10h	Reduced fleet size requirement	This is potentially as a result of improved operational availability/capability.		reduced cost of procurement/replacing equipment/platforms; savings on fuel, maintenance and spares; savings on inventory holding costs	Fleet managers, capability development/acquisition organisations, operational planners, strategic planners		1-3,5-7	+	L	I
10i	Difficulty in obtaining parts and technical knowledge as fleets age		Increased spare part cost, particularly if one-off runs to produce spare parts are required; research into substitutes				3,5-7	-	L	I
10j	Increased equipment down-time due to spare part obsolescence as fleet life is extended	This refers to the increase in down-time as spare parts become more scarce, and consequently harder to source, when fleets are extended beyond their nominal Life-of-Type.	costs related to reduced operational availability				3,6	-	L	I
11	**Human factor effects**									
11a	Resistance to change	There may be resistance to changes to associated maintenance and logistics processes, through perceptions of an increased training burden, increased complexity of equipment operation, the potential for job losses, and "spy in the cab" syndrome	Costs of delays in implementation of new technologies and processes; inefficient use of technologies		end-users, logistics personnel, maintenance personnel, operational planners, strategic planners, ADF policy-makers, fleet managers		1,2,4-6	-	S	D
11b	Lack of immediately observable benefits from data collection	If operators/maintainers cannot readily see the benefits of any 'additional' data collection, they are less likely to do it in preference to other work perceived as having greater importance.			Equipment operators, maintenance personnel, fleet managers, data analysts		4,6	-	S	D
11c	Reluctance to record and download relevant data by operators	Can be summed up by "if it is not easy to use, it won't be used".	Loss of potential long-term efficiency gains		Equipment operators, maintenance personnel		3,4,6	-	S	I
11d	Reduced accuracy of information underpinning decision-support		Loss of expected efficiency gains with operational decision-support applications		Logistics personnel, operational planners		1,4	-	S/M	I
11e	Cultivation of culture of equipment ownership/excellence			Reduced costs associated with inadequate care and inappropriate use of equipment/platforms	Equipment operators, maintenance personnel	That there is trust in CBM-generated equipment/platform health information	4,6	+	M/L	I
11f	Increased confidence in the use of equipment/platforms	Includes increased confidence in use of equipment as well as confidence in use of equipment beyong the expected equipment life		Reduced cost of replacing equipment beyond its expected service life but still in working condition	Equipment operators, passengers	That there is trust in CBM-generated equipment/platform health information	4	+	M/L	I

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11g	Improved operator performance	This may be achieved through e.g. enhanced or personalised training afforded by HUMS feedback		Reduction in costs associated with inappropriate/inefficient equipment use	Equipment operators	That personnel are employed who tailor training to individual operators	4	+	M/L	I
11h	Improved troop morale				Equipment operators, passengers, maintenance personnel		4,6	+	M/L	I
12	**Impact on mission effectiveness**									
12c	Improved situational awareness in terms of equipment/platform status		Cost of integration of CBM-generated information with C2 systems	Reduced labour and administrative costs involved in manual collection and collation of required information	Operational planners, logistics personnel, fleet managers	That relevant, effective and accurate information is available to facilitate situational awareness	1,3	+	S/M	I
12b	Improved decision support for mission assignment of equipment/platform		Cost of integration of CBM-generated information with C2 systems; cost of specific decision-support modules	Potentially reduced overall operational costs; avoidance of operational failure costs	Operational planners, logistics personnel, fleet managers	That CBM-generated equipment health information is utilised within mission planning processes; that relevant, effective and accurate information is available to support the decision-making process	1,3	+	S/M	I
12a	Improved mission effectiveness			Reduced costs associated with mission failures (e.g. delays, recovery, injury management); more efficient use of resources	strategic planners, operational planners, equipment operators, logistics personnel, fleet managers		1-7	+	M/L	I

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19. ABSTRACT
Condition Based Maintenance (CBM) involves performing preventive maintenance actions based on evidence of need, rather than more traditional usage or time schedules. This report presents interim results from a CBM 'Technology Impact' study that aims to identify the key drivers and factors that need to be understood for CBM to be effective in the military Land domain. Following a literature review and a first round of Subject Matter Expert surveys, a 'causal impacts' map has been established. This map considers the impact of the required enablers of a CBM capability and the likely outcomes of adoption. In addition, the map captures economic and temporal considerations, and impacts on stakeholder groups and Fundamental Inputs to Capability categories. This map will be further refined and analysed as the study progresses. The study outcomes will inform capability acquisition projects and collaborative research within The Technical Cooperation Program. Ultimately this study will form a basis for a 'value proposition' framework to assess the extent to which CBM should be adopted within Land materiel maintenance.

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